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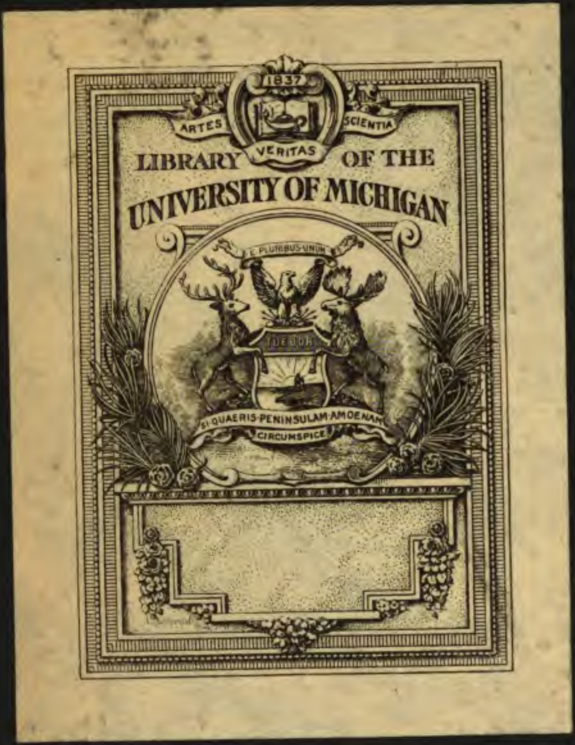
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ELECTRICITY:

ITS THEORY, SOURCES, AND APPLICATIONS.

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BY

JOHN T. SPRAGUE,

MEMBER OF THE SOCIETY OF TELEGRAPHIC ENGINEERS.

LONDON:
E. & F. N. SPON, 48, CHARING CROSS.
NEW YORK: 446, BROOME STREET.
1875.

PREFACE.

This work consists mainly of papers written for the 'English Mechanic,' together with other papers which have appeared in the 'Telegraphic Journal:' the whole has however been rearranged and in great part rewritten to fit the matter for its new form.

A few words upon the aim of the Author may prevent some misconceptions. This book is not meant to be a mere addition to the already numerous Text-Books which collect together a number of isolated facts and leave the reader to digest them as best he can; nor is it addressed mainly to the professional electrician or the practical manufacturer, though it is hoped it may be useful to both.

It is written chiefly for that large and increasing class of thinking people who find pleasure in the study of science, and seek to obtain a full and accurate scientific knowledge for its own sake, or as part of the necessary mental preparation for many of the departments of modern life. The object, therefore, has been to review the leading and essential facts and to so systematize them as to form of them a catalogue *raisonnée*, in which all information obtained elsewhere may be readily inserted, and be as readily available when required. Many mere facts found in all other books on electricity may here be omitted or only slightly glanced at; but, on the other hand, *principles* are dwelt upon, and the instruments necessary to their study fully explained, so that those who have some mechanical aptitude may construct them for themselves, the very best possible way of understanding them.

The application of the force to the processes of electro-metallurgy, however, has been dealt with from a practical point of view, and it is hoped that in this and also in other parts of the work, the numerous questions which for some years have been addressed to the writer in the pages of the 'English Mechanic' will have proved a guide to the particular points requiring attention, and the difficulties most likely to arise.

The subjects not fully entered on in this volume will be dealt with in future papers in the 'English Mechanic' (where also answers to any difficulties will be given), and may ultimately form another volume.

ELECTRICITY.

CHAPTER I.

INTRODUCTORY.

1. When we endeavour to analyze and simplify our ideas of the universe of which we form part, we find that we reduce it to three distinct conceptions, which we define as *Essences* or *Entities*, viz. Matter, Force, and Spirit. We cannot separate these or really conceive either one by itself, yet as mathematicians abstract particular qualities and functions and express them by symbols, so we do with these primary entities: the first we conceive as inert in itself, the second as that which acts upon and moves matter, and the third as that which controls both, and alone possesses volition and intelligence. We next develop in our minds the several forms and actions of these entities, and hence arise the two main divisions of human thought, each of which in turn assumes the higher importance, either in the individual minds adapted to them, or in the different periods at which men's minds have been more generally directed to one or the other of these forms of thought.

I. Physics, the study of the nature and relations of *matter and force*, pursued by means of *observation* and *induction*, and tested by *xperiment*.

II. Metaphysics, chiefly directed to the third great conception, and pursued by means of *observation* and *induction*, experiment being as yet inapplicable.

Physics are therefore the basis of all our real knowledge, while metaphysics, at best, have only attained to the position of "guessing at Truth."

Let us direct our attention to what branch of physics we may, it will be found wholly incomprehensible unless we also examine most other branches; hence the study of electricity can only be successfully pursued by first attaining clear general views of matter and force, and of those fundamental doctrines the details of which belong to the sciences of chemistry and mechanics. Chemistry has gone through such changes of late, and many of its terms and doctrines are so differently treated by different writers, that I think it better not to refer the reader altogether to works treating of this branch of knowledge, but to give here the necessary general outline of the facts, principles, and terms which will be employed, to serve as it were as an outline chart, by which we may afterwards travel intelligently through the land we desire to explore.

2. **Matter.**—Of the essence or nature of matter itself we know absolutely nothing, and never shall know anything; but of its properties, whether they be inherent in its own essence or due to the action of forces connected with it, we know a good deal.

Matter, as known to us, consists of certain forms which we call elements, because they are the simplest substances we have yet attained to. These may, for all we know, be composed of varying mixtures of yet simpler forms of matter; but true science, as distinguished from metaphysics, refuses to admit the "*may be,*" but rests on what is *proved.* Therefore, in science, matter means the elements and their compounds.

3. **Elements.**—Of these at present sixty-five are known. They exist as gases, such as hydrogen and oxygen; as liquids, like bromine and mercury; and as solids, such as carbon and the long list of metals; but these physical states are not essential to their nature, they depend only on their existing relations to force, as heat and pressure; and as we can, by altering the conditions of force, cause most of them to pass from one state to the others, so there is no reason to doubt that every gas can assume the solid form, and every solid become a gas, under sufficiently altered conditions of force.

4. **Atoms.**—There is abundant evidence that these elements exist in the form of ultimate particles called atoms, possessing definite dimensions and weight. Though these atoms are practically infinitely small and beyond our powers of measurement or even conception, yet their existence is not a mere hypothesis, but a logical deduction from well-proved facts. All the actions of matter prove their existence, and the whole framework of modern chemistry, and, indeed, of all the natural sciences, is based on the atom.

There have been many discussions as to the actual existence of atoms, which have been really battles about words. "Atom" means, in fact, incapable of division, and it requires no elaborate mathematical analysis to show that any particle having dimensions and weight, however small, must be theoretically capable of being divided: but we need not encumber ourselves with any hypothesis as to the atom being infinitely hard and so on, as subtle reasoners about things beyond our knowledge continually do; all we need is to consider the atom as the ultimate particle of each form of matter, and that if divided, it would no longer remain that form of matter.

The atom has several relations to force: (1) to gravity, which depends on its mass simply, without reference to its nature; (2) to heat, which for each physical form of matter is the same for all atoms; (3) chemical affinity, which varies between every different class of atoms.

5. ETHER.—Besides the ordinary known matter there appears to be something pervading all space, though so *thin* or attenuated as scarcely to come within the common idea of matter as something tangible. That it exists astronomy affords us actual evidence, but what it really is we have no means of ascertaining, because it is impossible to lay hold of and analyze it; but the more we learn of the actions which take place in our own and the other suns, the more probable it becomes that it is ordinary matter in an ultra-gaseous condition, but whether retaining the state of ordinary elements, or whether resolved into a more simple form, or even into a non-atomic state, we do not know, nor are we ever likely to learn except by deduction from its actions. But all systems of physical philosophy alike require this so-called "ether," for so far as the probabilities of several hypotheses are concerned, there is no difference between this one ethereal form of matter transmitting the impulses of the forces, and a luminiferous agent issuing from the sun, or an electrical fluid pervading space and matter, except that the first—the modern theory—is by far the most simple and most accordant with the facts needing explanation.

This hypothetical ether is being gradually made to fulfil more and more of the functions for which the older philosophers invented separate "fluids," and in this there lies a new danger for real science. We know absolutely nothing about the ether, and these applications of it are little more than guesses: but when a word is invented to cover a difficulty, people easily come to believe that this word actually explains the matter.

6. ATOMICITY OR VALENCY OF ATOMS.—Within the last few years chemistry has undergone a complete revolution, and one of the leading features of the new system is the idea of molecular types, these being due to the atoms having different exchangeable values. One of the oldest ideas of the atom was that matter had no real existence, and that atoms were simply centres of force. The modern idea is, that though the atom is a material body, it acts as a centre of force, and that the atoms of different elements differ by possessing one, two, or more such centres, or foci of influence. Hence the elements are classified as monads, monatomic or univalent, having only one attraction, such as hydrogen, chlorine, &c.; dyads, diatomic or bivalent, having two attractions, as sulphur, or

oxygen; triads, triatomic or tervalent, with three attractions, as nitrogen; tetrads, tetratomic or quadrivalent, having four attractions, as carbon, and so on.

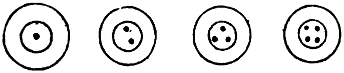
The words atomicity and valency are frequently used as synonymous; but there is a tendency to attach the first term more to the theoretical explanation of the nature of the atom, while valency expresses the fact that atoms of the weights now accepted do, in combination or substitution, replace 1, 2, 3, or 4 atoms of hydrogen. This involves no theory, and whenever I use the word valency it must be understood as expressing this fact, not as necessitating the explanation of which an outline follows.

7. It is conceived that the atoms of which matter is built up are not in absolute contact, but are separated by spaces (containing ether) in which they move freely under the several forces to which they are exposed, these motions replacing in modern theory the atmospheres of forces or fluids which used to be believed in. The atoms are held together by the attraction or force which we call affinity, exerted across these intervening spaces.

In any act of combination or decomposition, nothing less than one atom of any substance concerned can take part or undergo a change of its relation to other substances, but these relations are governed by the number of attractions proper to itself. Thus an atom of hydrogen (1) can only combine with one atom of chlorine (1) to constitute hydrochloric acid; two atoms of hydrogen (1) unite with one of oxygen (2) to form water; three atoms of hydrogen with one of nitrogen (3) form ammonia, and four with one of carbon (4) make marsh gas, these being four of the typical forms to which chemical combinations are referred, not merely for convenience, but because they are all bodies actually existing, and playing important parts in the chemistry of nature, and also because they are forms which would result from the several atomicities, if these really exist.

As to the actual shapes of the atoms we know nothing; but to enable readers more clearly to realize the theory set before them, I employ diagrams in which the several atoms are represented by circles containing dots to mark their atomicities, and surrounded by another circle to mark the space which separates them from each other and in which they move; but it must be understood that these diagrams are only aids to the imagination; they represent ideas, but by no means must be taken for actual pictures of the things they may aid us to conceive. We may therefore picture the various classes of atoms as in Fig. 1.

FIG. 1.



8. **The Molecule.**—Until very recently the words atom and molecule were treated as almost synonymous, but the rapid growth of modern chemistry has required a more exact definition of ideas, though even yet, as to compounds, the word molecule is not unfrequently used where atom or radical would be more correct. The strict meaning of the word now is the smallest quantity of a substance which is capable of separate existence as a free body. With this meaning the word is equally fitted for use in chemistry and in general physics.

It is therefore a body in which all the attractions or valencies are satisfied, leaving the combined atoms to act as a whole from one centre, so far as such forces as gravitation, cohesion, heat, &c., are concerned. A body whose atomic attractions are not thus satisfied, though it be complete in one chemical sense, and has a real existence, yet cannot exist by itself, and therefore is not a molecule but a compound atom or radical, because indivisible without change of nature; to become a molecule it must unite with another body or bodies sufficient to satisfy its attractions.

This applies equally to elementary and compound bodies, and therefore every molecule must consist of at least two atoms—distinct, yet united—and acting as a whole on surrounding bodies. Hence a piece of copper wire is not built up of atoms, as in Fig. 2, but the atoms are coupled together, first as molecules, as in Fig. 3.

Fig. 2.

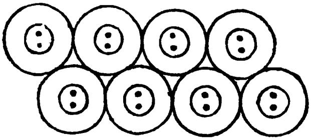
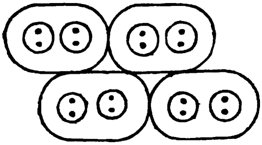


Fig. 3.



It is evident that as regards simple elements, two atoms, whatever their atomicity, can form a molecule by satisfying each other, and this is the usual form of elementary molecule; but there are some of which the molecule may probably contain several atoms, and others, such as carbon (§ 142) and phosphorus, which exist in several conditions, or allotropic states, the cause of which may be, that the molecules in these different states contain different numbers of atoms, but as this has no direct bearing on electricity, it need only be glanced at. (See § 29.)

9. **Molecular Types.**—When different elements enter into combination, the number of atoms forming the molecule will depend on the relative valencies of the several atoms, and hence we arrive at

certain typical forms or molecular skeletons, to which all compound bodies are related. A univalent atom can only join a single univalent atom, and this furnishes the first type, Fig. 4. Here the two atoms, 1 and 2, in molecule A, may be both hydrogen $H' H'$, or both chlorine, $Cl' Cl'$ forming the free molecule of hydrogen or chlorine; if 1 is hydrogen and 2 chlorine we have $H' Cl'$, the molecule of free hydrochloric acid; and if we substitute sodium for the hydrogen in this, we have $Na' Cl'$ the molecule of common salt, and if we now substitute iodine for the chlorine we have $Na' I'$ iodide of sodium. Fig. 4 A, in fact, shows a molecular frame, which we may fill up at pleasure with univalent substances without destroying the molecular constitution, and when submitted to the action of an electric current, the body, be it what it may, which occupies the position of atom 1, will always appear at one pole, and atom 2 at the other pole.

The molecular equilibrium will not even be destroyed if we substitute a compound atom or radical for either or both of these atoms; thus returning to the sodium iodide, the iodine may be replaced by cyanogen Cy' (which being $C^{IV} N'''$ has one attraction unsatisfied) producing sodium cyanide $Na' Cy'$, and then finally the sodium may be exchanged for the monatomic radical of alcohol, ethyl C_2H_5 to form cyanide of ethyl. I have gone somewhat fully into this type, in order to give the general principle applicable to all—viz. that any typical atom in any molecule may be replaced by another atom of similar valency, without altering the arrangement of the molecule, and in so doing its chemical properties will only be gradually affected, according to the properties of the substituted atoms, without changing its relations to electrical force.

FIG. 4.

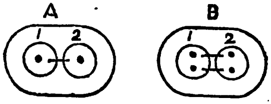
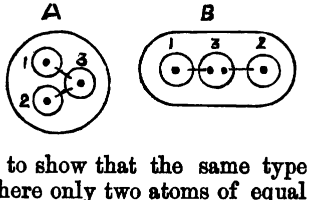


FIG. 5.



Molecule, B, in Fig. 4, is intended to show that the same type includes bodies of higher valency, where only two atoms of equal valency, each satisfying the other, are contained in the molecule; so that this type includes the molecules of the elements, and of many radicals in the free form, though A, Fig. 4, is that which is called the hydrochloric acid type.

The next is the WATER TYPE $\left.\begin{matrix}H\\H\end{matrix}\right\}O$ or H_2O, in which one diatomic atom unites with two monatomic atoms.

Here, as in the first and in all other molecular forms, each atom is capable of being exchanged for any other of equal value: thus, the hydrogen atom 1 may be replaced by potassium, and we have $\left.\begin{matrix}K'\\H'\end{matrix}\right\}O''$ hydrate of potash; again, 2 may be similarly replaced, giving $\left.\begin{matrix}K'\\K'\end{matrix}\right\}O''$ or K_2O, potassium oxide; or instead of the hydrogen, the oxygen atom 3 may be exchanged for another diatomic atom, as sulphur giving $\left.\begin{matrix}H'\\H'\end{matrix}\right\}S''$ or H_2S, sulphuretted hydrogen.

Two ideal forms of this molecule are given, because neither will convey the whole truth, for we may conceive that both the hydrogen atoms are equally held to the oxygen in water, which is the form A, or one of them may be held more strongly than the other. There is good reason to suppose that the latter is the case in ordinary circumstances, and that atom 1 of the H is more closely united than 2 to the O; that HO first form a monatomic radical known as hydroxyl, to which the second atom of hydrogen is united. A strong support to this idea is found in what are called isomeric bodies, containing exactly the same elements in the same proportions, yet having somewhat different properties. It is evident that in Fig. 5 B there would be a difference according as atom 1 or 2 was replaced by another element. Still, Fig. 5 A is also true, for both 1 and 2 may be removed together and replaced by a single diatomic atom, in which case, however, we should consider the type was changed to that of Fig. 4 B: also, under the influence of an electric current, there is good reason to suppose that the molecule takes the form A, the atoms 1 and 2 passing to one pole, and atom 3 to the other pole. It is not necessary to go farther into the subjects of the types of molecular construction until the action of the electric current in electrolysis has to be considered; at present the main thing is to obtain a clear conception of molecules as the ultimate particles of matter in all its ordinary forms; as the bricks, so to speak, with which the substances known to us are constructed on regular systems of architecture, and to comprehend that they have a capacity of separating into at least two parts, which are held together by a mutual attraction.

10. It will be seen that there are thus two classes of molecules.

(1) *Molecules, which are also atoms,* being indivisible without change, as water, and all salts and acids. These molecules are held together by high affinities, varying in each case, and require considerable force for their decomposition.

(2) *Molecules formed of two similar atoms* or radicals, held together by their unsatisfied attractive foci, but by a feeble affinity;

these are capable of division into two similar parts, and that by a small expenditure of force. This is the state in which exist, as free bodies, the elements, and those compound radicals, such as cyanogen, which have many of the properties of elements, though known to be compounds.

11. We may conceive the molecule as representing on the infinitely small scale the solar system itself, which is built up of several systems or parts, each complete in itself, yet all linked to each other and forming a balanced whole: thus Mercury and Venus stand as single atoms, the earth, Jupiter, and Saturn, with their moons, resemble the compound atoms or radicals composed of several distinct atoms so united as to play the part of a single atom in the mighty molecule, which again forms but an infinitesimal part of the complete universe, held within it by forces acting across infinite space as our molecules are united into visible substances by the forces of cohesion, &c.

The various chemical facts and reactions are concisely expressed in symbols, which generally are the first letter of the name of the element in English or Latin: each such symbol stands for 1 *atom* of the element, multiplied when necessary by a small figure following it a little below the line: all reactions are expressed by first writing in symbols the construction of the substances set to act upon each other, divided by +, and then the substances produced, and the two should exactly represent the total atoms engaged.

12. NOTATION.—There are many modes of expressing the same things in different formulæ according to the special theory of constitution adopted, or the particular view of the matter intended to be described; and there are two distinct systems in use.

(1) *The Equivalent.*—This system, used in all the old books, is based really on oxygen (which was called 100), and the weight of hydrogen which combined with oxygen being called 1, the equivalents of other substances were afterwards reckoned from this. Hence water is in this system called $\underset{1}{H}\underset{8}{O} = 9$.

(2) *The Atomic.*—This, which is called the "New Notation," is generally adopted in all modern chemical books. It is based on the fact that water contains two *measures* of hydrogen to one of oxygen, and this being conceived to show the atomic relations, water becomes H_2O, and H being called 1 as to weight, it becomes necessary to call $O = 16$, and in consequence most of the metals have their weights similarly doubled as compared with the equivalent notation, while the number of atoms of those which are unchanged (the univalent elements) have to be doubled. The following example of the action of sulphuric acid upon nitrate of soda exhibits the two systems:

Equivalent.

$$\begin{array}{ccccccc} \text{Salt.} & & \text{Acid.} & & \text{Salt.} & & \text{Acid.} \\ Na\ NO_6 & + & H\ SO_4 & = & Na\ SO_4 & + & H\ NO_6 \\ 23\ \ 62 & & 1\ \ 48 & & 23\ \ 48 & & 1\ \ 62 \end{array}$$

Atomic.

$$\begin{array}{ccccccc} \overline{2Na\ NO_3} & + & H_2\ SO_4 & = & Na_2\ SO_4 & + & \overline{2H\ NO_3} \\ 23\ \ 62 & & 2\ \ 96 & & 46\ \ 96 & & 1\ \ 62 \end{array}$$

This means that the nitrate of soda on being mixed with sulphuric acid is decomposed into sulphate of soda and nitric acid. (See also example, § 152.)

13. **Force or Energy.**—This we know only as manifested by matter, nor can we form any idea of it as a separate existence; the teachings of modern science tend to bring all force under the simple definition of motion, excepting as yet a power or powers of attraction which may be inherent in the nature of matter. As some of the most interesting characteristics of Force are commonly overlooked, and thus imperfect conceptions produced, it is desirable to indicate the relations of energy to matter by means of a definite classification. Thus we may regard the forms of energy as:

I. Forces connected with matter as such simply. The chief form of such force is attraction, as gravitation, the degree of which depends simply on the absolute quantity or mass of matter, without reference to its nature; as cohesion, on which the strength of materials depends, though this does vary with the nature of the matter, and is also related to the molecular forms; and as adhesion in its many forms; of the nature of these forces we know nothing as yet, but they are grouped under the term Attraction.

II. Mechanical energy, or motion of matter as such, which, like gravitation, is connected with the absolute weight of matter in motion, and is measured by its power of overcoming the first class; its common unit in England is the foot pound; that quantity of force required to raise one pound weight one foot against the attraction of gravity.

III. Force related to the *atom* of matter. Heat does not act on matter by weight or by bulk, but atom by atom. This discovery has played a very important part in chemistry of late. Each element has its own atomic weight, and hydrogen, being the lightest, is taken as unity; thus the atom of iron weighs as much as 56 atoms of hydrogen, copper 63·5, silver 108, gold 197. If these relative weights of the several substances are exposed to heat, and all raised to the same temperature, and are then each transferred to an apparatus capable of measuring the heat they have absorbed, it will be found that, different as are the quantities of matter in each case, they have all absorbed exactly the same quantity of heat. Of course the experiment is so delicate and difficult that perfectly exact results cannot be obtained, and as different mechanical work is done in each case by difference of expansion, certain corrections have to be made; but the deduction is absolutely certain, that heat acts upon matter, not according to its weight, but according to the number of atoms it contains.

This is readily comprehensible on the theory that heat is simply a vibratory motion, for it is evident that the atoms of the substance vibrate over a wider space, as they are more highly heated, and so transmit this amount of vibration.

The relation of compound substances to heat is not so simple as that of elements, though still a distinct law is traceable throughout; each molecular form has its own relation to heat, which is due to the number of atoms it contains, and their state of combination.

IV. Force related to the *molecule* of matter: such are the forces of electricity and magnetism which depend on the motion and polarity of the molecules. Heat also is related to the molecule in connection with internal work, such as expansion and resistance to pressure, and also as to the latent heat of fluidity; that is to say, there is a motion of the molecule as a whole, as well as a motion of the atoms within the molecule. Hence we learn that in the gaseous state, under the same conditions of force, all molecules, whether simple or complex, occupy the same space, so that heat and pressure produce the same amount of expansion or contraction upon all, proving that the force is acting upon the molecule as a whole, not upon its component atoms; and it is the same with the latent heat of fluidity, because the passage from the solid to the fluid or gaseous states is dependent upon the increased distance of the molecules, which neutralizes the attraction they exert on each other by causing them to move through wider spaces.

V. Force related to matter in the form of ether. This includes light, and any forces known or not as yet generally known (for there are such), which are transmitted to us from the sun.

This classification appears very suggestive, as throwing light on many obscure subjects, especially when combined with the now recognized fact that all the forces are capable of transformation into each other; it enables us to conceive that if the undulations of the ether produce the effect which we call light, those same undulations, when transferred to the material atoms floating, as it were, in the ether, produce the effect we call heat; and thus we may apprehend the reason why heat and light are so constantly coexistent, and also see why it is that while the sun transmits us such a constant supply of heat as well as light, yet to all appearance the space between the sun and us is actually devoid of heat. (See § 104.)

14. The phenomena classed under the name of electricity are among the most striking presented by Nature and science, and their study is one of the most fascinating upon which the mind can engage. Yet, although the natural exhibitions of electricity in thunderstorms must have from the first arrested the attention of mankind, and although many scattered facts bearing upon the subject were known from very early times, still the science itself is entirely modern, and has only very recently assumed its true place in the field of knowledge.

The mysterious nature of the force inevitably led to a great deal of vague hypothesis in the early days of its study, and explanations were invented to satisfy the natural craving after the "Why," before knowledge had sufficiently advanced to enable a sound theory to be formed. So also minds of wide scope saw that, although electricity was regarded as a "fluid" or special entity, yet it was in some way closely connected with all the other natural forces; and from the evident relation between its phenomena and those of heat and magnetism on the side of matter, and its equally evident connection with nervous force on the side of vitality and mental action, there was a strong temptation to regard electricity as the fundamental force of Nature—the direct link between the Creator and his works.

Only recently, and as a consequence of the complete conversion of the scientific world to the opinion that heat is a "mode of motion," has electricity begun to take what is evidently its true place, as one of the phases of force or forms of motion, and yet only by thus regarding it can we possibly obtain a clear conception of Nature and a perfectly satisfactory explanation of Nature's phenomena.

But while scientific men are fast coming to this view of electricity, and it is very commonly employed, more particularly in connection with dynamic electricity or galvanism, still the new theory is rarely fully set forth and substituted for the old fluid theories, and therefore it is very difficult for students to obtain that clear view of the subject which is desirable, especially as all the terms of the science were devised in connection with the old theories, and are exceedingly ill-fitted to convey the new one without producing much confusion of ideas.

This work in its original form was intended to meet this requirement, and the plan adopted has been to commence with a few leading facts and principles, then describe the various forms of instruments necessary to examine the actions of the force, and by their aid trace out the general laws and fundamental principles of the science, after which the applications of the force of which the nature has been thus examined will become far more intelligible than by piling up isolated facts, or describing mere processes, however practically valuable.

To do this in a perfectly methodical manner is always more difficult in a natural science than in mathematical studies, because it is impossible to understand the most elementary facts without a considerable acquaintance with the subject; and, on the other hand, to lay a wide foundation in elementary facts before dealing with their theory would not fulfil the purpose of both leading the beginner in the best course and showing the more advanced how to adopt the new interpretations and to free themselves from the mental confusion produced by the old theories, while at the same time furnishing the practical man with the interpretation of the processes he employs.

CHAPTER II.

STATIC OR FRICTIONAL ELECTRICITY.

15. It is now generally admitted that mechanical motion is convertible into heat, and the effect of friction is a familiar illustration of this. For instance, if we turn a grindstone, it requires a certain force to start it, and then a certain amount to keep it in motion, to overcome the friction of its bearings and the air, and then so much more as is needed to overcome the resistance of any object we press against it, this body being heated in proportion to that pressure. If we get the stone into rapid motion, and then cease to work at it, it will run a certain time before stopping; but if we hold against it a piece of steel, it will come to rest in much less time, because its motion is absorbed by the friction; and if the stone is dry, we see a shower of sparks fly off, visibly exhibiting the transformation of this motion into heat.

But if we cover the edge of our grindstone with certain substances, guttapercha for instance, and establish certain other conditions, we can obtain a very different result; instead of heat we have electricity developed. When we ask, whence does this electricity come? the modern doctrines I am now setting forth teach us that it is, like heat, the mechanical motion converted into molecular motion; that which of these forces we shall obtain depends entirely upon the conditions to which we expose the molecules; and further, that as soon as we allow the electricity to act, it either passes into heat, as we see by the spark, or else does some work which represents the heat.

16. This development of electricity by friction was observed in early days, and we derive the name itself from *electron*, the Greek name for amber, the substance by which the phenomenon of attraction after friction was first manifested. In later times it was found that many substances possess this property, and such were called "electrics," and those bodies which do not appear to possess it, "non-electrics." The distinction is more apparent than real; for under certain conditions, both classes develop electricity under friction, the true cause of the difference being the different power of substances to conduct electricity, on which property is based

another classification into conductors and non-conductors: but here again increased knowledge has shown that no such broad definition can be sustained, the distinction being one of degree only, not of essential property. All substances are electrics, and all conductors, though some conduct only very slightly. Faraday, finding that conduction was effected by "induction" of polarity from molecule to molecule, introduced the term *dielectric*, to convey this conception, and the term is commonly used now in the sense of a body which transmits electric induction, but chiefly as limited to those which do so slowly, or those which stand highest in the list of electrics. With this understanding of the meaning of the terms, as relative and not absolute, the classification has much practical value, and the following is a list of ordinary substances, in which, as we descend, each one is a worse electric and better conductor than its predecessor.

Electrics, Dielectrics, or Non-Conductors.

Ebonite.
Shellac.
Paraffin.
Guttapercha.
Amber.
Resins.
Sulphur.
Wax.
Glass.
Mineral crystals.
Silk.
Wool.
Furs.
Dry paper.
Dry leather.
Baked wood.
Porcelain.
Dry ice, below 13° F.
Crystals containing water of crystallization.
Dry earths.

Non-Electrics, or Conductors.

Oils in the order of their specific gravity.
Metallic oxides.
Smoky flames.
Vapours of alcohol and ether.
Rarefied air.
Living animals and vegetables.
Ice and snow, above 13° F.
Rain water.
Spring water.
Sea water.
Solutions of salts.
Dilute acids.
Powdered carbon.
Strong acids.
Plumbago or graphite.
Well-burnt charcoal.
The metals in order, silver being the best.

17. We may now pass to experiments, from which alone knowledge is to be obtained. This is the only royal road, for mere reading will never give a knowledge of science. For this reason I shall indicate such simple forms of instruments as anyone can obtain or make for themselves, but which will, if carefully studied, go far to demonstrate principles. The first things needed are a source of electricity, an indicator of its presence, and then the means of collecting it and examining its actions.

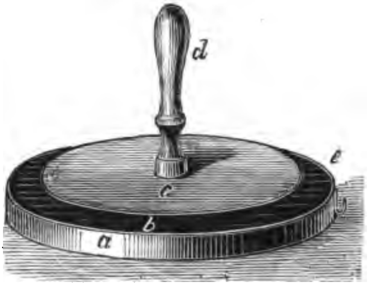
18. If we take a stick of sealing-wax, or a rod of glass, in one hand, and rub it with a piece of dry cloth or fur, we have the

fundamental experiment from which electrical science grew, for we find that we have developed a force upon, or induced a condition in, the rod which enables it to attract and repel light substances; and the same effect may be produced by rubbing a vulcanite comb on the sleeve of a coat.

If we examine the conditions of this experiment by the light of advanced knowledge, we find they consist in the presence of (1) a dielectric in contact with (2) the conducting body of the operator; (3) another electric in similar contact; (4) mechanical motion, or friction of the two electrics; and (5) separation of them when the friction is ended. These conditions include every instrument devised for developing electricity by friction, and they may be applied in the simplest form.

19. THE ELECTROPHORUS.—This is the simplest source of electricity next to the mere rod; it has many forms, but its principles are the same as that of the rubbed rod. A common form is shown in Fig. 6. *a* is a circular tin dish into which is run *b*, which may be sulphur or any resinous substance. A cheap electric may be made with 8 parts of resin, 1 of shellac, and 1 of Venice turpentine or wax, well melted together and run into the dish *a*; *e* is a hook soldered to the tin dish, for convenience of attaching a chain as a conductor. The dish forms the conductor from the dielectric to the earth, as all electrical books tell us, an error which will come up for examination by and by; but whether to the earth or not, at all events through its supports, such as tables, &c., to the body of the operator, who rubs the face of the disc with a piece of flannel or fur, or a silk pad covered with electric amalgam. A means of collecting the electricity from the surface is now required, and this is C, the cover, consisting of a piece of sheet metal, or smooth wood covered with tinfoil, and having a handle *d* of glass or well-baked and varnished wood.

FIG. 6.



20. It is desirable here to remark that glass, though one of the best non-conductors, has the property of condensing a film of moisture on its surface, and thus becoming a conductor. Therefore, those parts of electrical instruments which are made of glass, should, where possible, be covered with a varnish which has less

attraction for moisture. This applies to the handle of the electrophorus cover, the legs of insulating apparatus, and the faces of electrical machines, in those parts which have not to be rubbed. The varnish should be moderately thin, so as to require several coats, rather than one of a thick varnish. I have found the best is made by dissolving 1 lb. of shellac in one pint of the strongest methylated spirit (polisher's finish will do), and then adding to it, say, one-twentieth of its bulk of a solution of indiarubber, just thin enough to run freely; a solution in bisulphide of carbon answers. This, when it dries, forms a tough coherent surface, and adheres strongly if the glass be warmed before applying it: it is also a good cement for joining glass.

Also in all electrical experiments, it is desirable to slightly warm the apparatus, and to work in a room, the air of which is dry and moderately warm; when the air is moist, success is scarcely to be attained.

21. **The Electroscope** is an instrument for evidencing the presence of electricity. Fig. 7 is the simplest form, being a glass rod mounted on a stand, and bent at the top into a hook, from which hang, by silk thread or hair, one or two pith balls. Fig. 8 is a more elaborate contrivance; it is a glass bottle; on opposite sides of the inner surface are pasted strips of tinfoil, which are continued to the outside and to a brass ring fitted with a hook, to which chains may be attached. Through the cork passes a small tube, closed at the bottom, to which are fixed two strips of gold leaf. The bottle should be well dried and warmed, and the cork cemented in and coated with shellac varnish: when the loose fittings *e* or *g* (Fig. 9) are inserted it is a simple gold leaf electroscope; *f* is a metal plate covered with a coating of shellac on

Fig. 7.

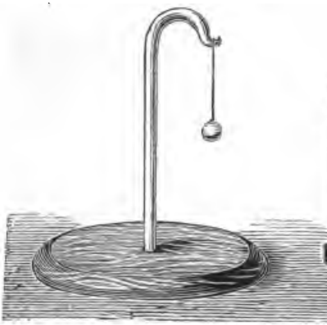


Fig. 8.

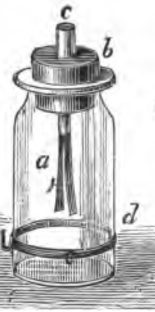
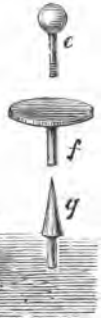


Fig. 9.



its upper face, and when this is fitted to the instrument and an exactly similar plate with an insulating handle placed upon it, we have a condensing electroscope. The lower plate is connected to the source and the top of the upper plate touched with a conductor to "earth"; on removal of this conductor and then the upper plate, a far greater divergence of the leaves is produced than if the source had been connected to them directly, as will be readily understood by the explanations given in connection with Fig. 26, §§ 58, 59. Connected as described, the leaves exhibit the same electricity as the source; the effect will equally be produced if the process is reversed and the upper plate connected to the source, but then the leaves exhibit the opposite condition.

It may also be desirable here to mention how the nature of the charge is to be ascertained, as the electroscope diverges alike with positive and negative. They are instantly distinguished by rubbing a piece of ebonite, and approaching it to the instrument; if this is charged with +, the leaves will approach each other; if with – the divergence will increase; both effects are temporary, and cease when the ebonite is withdrawn; with excited glass the action would be reversed. A similar process is useful in testing feeble charges; if the electroscope is charged slightly with + electricity, when approached by a + charged body the leaves will increase in divergence; on approaching a – body they will collapse.

These instruments only indicate the presence of electricity; to measure it electrometers are employed as described § 72.

22. One of our standard electrical works says (and it is just what all say), "*Vitreous* substances, such as glass, become electrical by being rubbed with certain other substances; in this state they attract light bodies. *Resinous* substances, such as sealing-wax and guttapercha, become also electrical when rubbed with certain other substances; in this state *they* also attract light substances. Bodies which have been once attracted by excited glass or excited resin will not be attracted by the same substance again until they have touched some body in communication with the earth, but will be repelled. A body which, having been attracted by an excited *vitreous* substance and is then *repelled* by it, is *attracted* by an excited *resinous* substance; so also a body which is repelled by an excited *resinous* substance is attracted by an excited *vitreous* substance."

23. These statements are received as absolute truth by electricians, and upon them the fluid theories of electricity are based; and yet there is scarcely a truth in them which is not overweighted by an error, and the simplest facts even are erroneously stated.

Let us see, by the aid of the simplest experiments, which everyone ought to perform for himself. Our vitreous substance may be a piece of stout glass tube. (N.B.—It must be kept warm to get any good effect.) For our resinous substance we take a piece of ebonite, the very best and strongest electric; the back of a comb will do, or a slip cut out of a thick sheet. A silk handkerchief is the readiest exciter, or a piece of flannel will do very well.

Fig. 10.

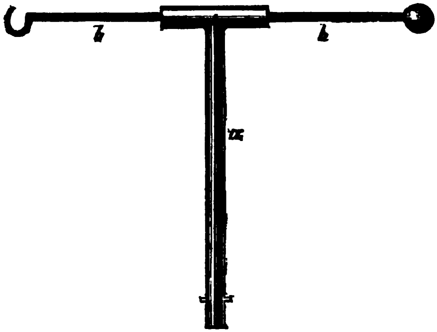


Fig. 10 illustrates a form of electroscope devised expressly for these experiments, which gives effects not readily noticed in other forms. It is simply a brass rod *a*, ending in a tube through which slides a wire *b*, one end finished with a lump of guttapercha or glass bead, and the other with a hook, for the pith ball or balls; a stand fitted with a glass stem and a short socket, in which *a* can be inserted, and also available for other purposes, completes the instrument.

24. Let a pith ball be suspended by a very fine and dry hair or silk fibre, and the excited electric be presented; the ball will be first strongly attracted, and then steadily repelled; but if an excited electric of the opposite order be presented it will attract the ball, and then, if capable of reversing its charge, will repel it.

Hence it is stated, as a fundamental law, that bodies similarly electrified repel each other, *which is not true*, so stated. Moisten the suspending fibre slightly, or substitute a ball suspended by a very fine wire, and no *repulsion* will occur; the ball may be led up above the stand, and the electric raised slightly till a point is reached, at which the ball will float as it were in the air, the attaching fibre hanging loose, apparently having nothing to do with the ball, which thus acts the part fabulously attributed to Mahomet's coffin. Why does repulsion occur in the one case and not in the other? If the excited electric be held over a table on which are laid some loose pith balls or pieces of paper, &c., these will fly up to it, and back to the table, rapidly repeating this process till the electric excitement is considerably reduced, or till the electric is taken farther away; then the light bodies will firmly adhere to its surface. If the supposed repulsion really existed, it is obvious that these bodies, which are of course similarly electrified by contact with the electric, *could not be held* firmly to it. If the electric when excited be placed apart from all surrounding bodies, in a dusty atmosphere and in a beam of light, it will be seen to attract the floating particles and hold them without at all repelling them after contact. In fact, the repulsion is only apparent, the real cause of the motion is to be found in the attraction exerted by the surrounding bodies.

If two balls are suspended side by side and touching, by dry hairs, they act like the single one, first touching and then flying from the electric; on removing this, they fall together, but will not quite touch; they apparently exert a mutually repulsive action, which increases on the approach of the electric, and also if on each side an unexcited body is approached. If, while the balls are separated by this apparent repulsion, an excited electric of the opposite order is brought near, they will fall together: the hand which holds the charging electric itself, or a finger of the other hand, will also act as an electric of the opposite order.

These experiments may be varied in almost endless forms, and the actions noted with various suspending fibres, and with the stand of the electroscope insulated or connected to earth: from them, and others to be considered later, are derived the various theories of the nature of electricity.

25. THE TWO-FLUID THEORY.—When it was found that the electric excitement produced by glass was opposite in its nature to that existing in amber and resins, the earlier experimenters were led to imagine that there were two "fluids" pervading matter; that each of these fluids exerted a strongly repulsive action on its own parts, or bodies separately charged with itself, but that each fluid had a strong attraction for the other, and both a strong attraction for ordinary matter; that in the ordinary condition of matter the two fluids were united in equal proportions, being thus neutralized and adherent to matter. Some have supposed that the two fluids when thus united constituted another hypothetical fluid, caloric, or heat.

It was supposed that by friction of some substances, thence called electrics, these two fluids were separated, the one remaining on the surface of the electric, the other on the rubber, and that from these either could be transferred to insulated bodies, that is, to substances which furnished no pathway along which the disunited fluids could find a way to the re-union intensely sought by both. Hence, when a charged body or an excited electric is presented to a light movable body, the latter is drawn towards it by the attraction of the fluid for matter; as soon as the charge is equally divided, the self-repulsive property of the fluid causes the two bodies to be repelled, and then if a body similarly charged with the other fluid is within reach, attraction occurs, the fluids re-unite, with a spark if the quantity and tension are great, and resume their usual neutral state. But if there is no such oppositely charged body accessible, any body in conducting connection with the earth will enable the charge to dissipate itself, as some say, because the earth is a comparatively infinite reservoir of both fluids, but more simply and more in accordance with the theory itself, because it presents an unlimited surface and body of matter; and the fluid distributing itself over all surfaces and matter to which it has a conducting path, the charge, which is great upon the small surface of the electrified body, becomes nothing when it has the whole earth to spread itself over. This hypothesis was built upon the phenomena of frictional electricity, and of these it furnishes a moderately satisfactory explanation.

26. **The One-Fluid Theory** was devised by Franklin, as more simple than the other. He supposed that there was one electric fluid pervading all matter, possessing a strong attraction for matter, but being strongly self-repulsive: matter in its ordinary state has in connection with it so much fluid as satisfies the mutual attractions, but when certain bodies (electrics) are rubbed, some absorb part of the electricity from the rubber, and thus become *positively* charged with this overplus; others part with their proper electricity to the rubber, and thus remain themselves *negatively* charged. As with the other theory, the earth is supposed to receive the electricity driven off, or to supply any quantity of it when needed. This theory also explains the ordinary phenomena of static electricity, and on it Berzelius built his electro-chemical theory, which ruled chemical science for many years, treating the relative affinities of different substances as due to the relative proportions of electricity belonging to them.

27. All the terms of electrical science have grown up from these theories, and hence we have

$$\begin{array}{c}\begin{array}{r}\text{VITREOUS.}\\ \text{Positive}\\ +\end{array}\left\{\begin{array}{c}\\ \text{and}\\ \\ \end{array}\right\}\begin{array}{l}\text{RESINOUS.}\\ \text{Negative}\\ -\end{array}\\ \text{Electricity.}\end{array}$$

Also the words charge, quantity, conduction, accumulation, and distribution, which imply the passage of something having a real separate existence; these and similar terms we are obliged still to use, but I will define the meanings they are to convey in this work. The last terms and their signs will be those used, as they are generally known, but they will not be used as conveying the idea of an excess or deficiency of a fluid, but simply as expressing opposite polarities of matter.

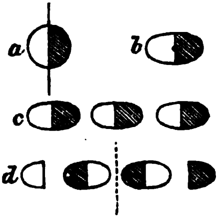
28. THE MOLECULAR THEORY was founded by Faraday in his memorable experiments on induction, but it has since grown with the growth of the other sciences; it is a necessary sequence to the now established doctrine of heat being motion, and is intimately connected with the more modern and rapidly advancing doctrines of chemistry. Simply stated it is, that electricity has no existence, but the phenomena we call electrical are due to properties and motions of the molecules of matter, to comprehend which we must now return to the consideration of the molecules themselves and their mode of arrangement into the usual forms and substances known to us. Of late there has been a tendency to attribute the actions of electricity to motions of the supposed ether (see § 5), which is considered to be in some way condensed upon the material molecules: this idea is naturally most favoured by mathematicians; it is unnecessary to consider it, and to all but trained mathematical minds it is nearly incomprehensible, and appears only a modification of the old one-fluid theory: if the ether is so condensed, it becomes a part of the material molecule and the cause of its actions, and therefore all that is really known can be studied by considering the molecule as possessing certain properties now to be studied, leaving in suspense, as beyond our present knowledge, the cause of those properties.

29. Our former consideration of the molecule (§§ 8, 9) related to its chemical constitution. We have now to examine its physical character—internal, as regards the manner of its existence and breaking up, and external, as to its attractions for and relations to other molecules; and we have to consider it as a body composed of two distinct parts linked together, but acting also as a whole from a common centre. Tyndall's words, when describing the actions of light, heat, and pressure on gases, convey the idea very fully: "Molecules do separate from each other when the external pressure is lessened or removed, but the atoms do not. The reason of this stability is that two forces—the one attractive and the other repulsive—are in operation between every two atoms, and the position of every atom—its distance from its fellow—is determined by the equilibration of these forces." "The point at which attraction and repulsion are equal to each other is the atom's *position of equilibrium.*

If not absolutely cold—and there is no such thing as absolute coldness in our corner of nature—the atoms are always in a state of vibration, their vibrations being executed across their positions of equilibrium."

This means that the internal attractions of matter draw the atoms together; the forces of heat, &c., as motion, tend to separate them; and (the molecule being constituted by the balance of these forces) additional force tends to separate the atoms, and break up the molecule. We may now simplify our conception by Fig. 11*a*, in which we represent the two halves of the molecule as vibrating, under the influence of the undulations of heat, on a central point and vertical line.

Fig. 11.



Now suppose a force exerted which either intensifies those oscillations, as, for instance, heat, or which sets up a revolution of the entire molecule on the same centre and line, the effect would be to alter the molecule to Fig. 11*b*, in which it is obvious the internal attractions are weakened. If we now conceive a line of such molecules, Fig. 11*c*, we see that there must come a time when the atomic attractions will be greatly weakened internally and partly exerted on the corresponding or complementary parts of neighbouring molecules. In this state the substance may be said to be polarized. The degree of this tendency would be called its tension, being the strain upon the attractive forces; as this increases there comes a period when the molecules break up and re-form, as shown in Fig. 11*d*. This will be a discharge. The extreme atoms here may be considered either as forming parts of a continued chain, or as set free.

Faraday's theory of induction by polarization of adjacent molecules, though the origin of this conception, is very different from it; he was treating of the actions of a body charged with one kind of electricity, and the mode in which it produced electrical actions on surrounding bodies, but later discoveries have developed that theory of the *effect* of electricity in the form of charge, into a theory of the *source* or *cause* of electricity itself: this theory, which is the one adopted in this work, may be thus defined.

Electrical action is developed only when a complete chain of polarized molecules can be formed. When that chain is wholly composed of conducting molecules, dynamic electricity is manifested; when the chain is partly composed of non-conducting molecules, we have static electricity. The distinction between the two is the presence or absence of the conditions of discharge. (See also § 32.)

30. We are now ready to examine the conditions under which,

and the reasons why, friction develops electricity; and first, one glance at the utter improbability of the "fluid" explanation of this. The fluids have a strong attraction for each other and for matter, yet the rubbing of two substances together is sufficient to separate the fluids from each other, and the matter with which they are in quiet union. They have a strong repulsion for themselves, yet, in addition to overcoming these attractions, we collect these self-repulsive fluids into separate reservoirs. At the instant of doing so these reservoirs are in actual contact, yet the fluids do not reunite there, though they will do so with great violence when again brought into somewhat near neighbourhood, and travel any distance to get the opportunity.

Looked at thus, it is obvious that such a theory could only have been formed in the determination to make some kind of explanation of striking phenomena newly discovered, and that it has held its ground simply from habit and the gradual training of everyone's mind to study the phenomena only by means of it.

Whenever two solids or a solid and a liquid are rubbed together, electricity is developed; gases do not appear to produce this effect, but we need attend now only to the special phenomena of ordinary electrical excitement. We have hitherto treated glass as becoming positive by friction, developing vitreous electricity, but this is not an absolute fact; if, instead of a piece of silk for a rubber, we use a piece of cat's-skin, the glass becomes negative. The exact relation between various substances is stated variously by different experimenters: the following list (given in Ganot's 'Physics,' and probably the most correct) shows the bodies which when rubbed together develop positive electricity in the first and negative in the one which is lower in the list:

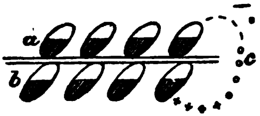
+ Cat's-skin.
Glass.
Ivory.
Silk.
Rock crystal.
The hand.
Wood.
Sulphur.
Flannel.
Cotton.
Shellac.
Caoutchouc.
Resin.
Guttapercha.
Metals.

We may certainly deduce from this list, that the nature of the substances in friction has a great deal to do with the result, and probably the most complete examination into this point was made by Coulomb, whose conclusions were, that those bodies whose parts are least disturbed by the friction tend to become positive, particularly if compressed; those which are most disturbed become negative, especially if dilated.

31. This implies simply that molecular disturbance is the cause of the electricity; and the deduction is very plain, that when two dissimilar substances are rubbed together, a certain amount of

adhesion is produced, and adhesion is attraction of a nature closely resembling cohesion; it is simply an external attraction, as cohesion is an internal one. This attraction, therefore, is to some extent opposed to the natural state of the bodies; it tends to draw the superficial molecules away from their neighbours; the opposing or complementary halves of these tend to unite, and therefore the internal attraction of the molecules themselves is weakened—they are polarized; Fig. 12 conveys an idea of this effect. The superficial molecules react on their neighbours; and a complete chain of excited polarized molecules is formed, along which is transferred the motion arrested by the friction, or rather the mechanical energy which but for the friction would have generated motion. It does so in any case; but if there be no resistance it effects that which we see and familiarly call motion; if there is resistance, we have the motion among the molecules, which is electricity, and this again exhausts itself by transmission to neighbouring matter in the vibrations of heat. If the two superficial rows of molecules are readily susceptible of mutual decomposition, immediate discharge occurs, if that is rendered possible by the whole chain of molecules being conductors, and then no static effects are produced.

FIG. 12.



Here we have a simple theory which unites Static and Dynamic electricity, and explains alike the excitement by friction, contact, chemical action, and heat. All are due to calling into action the latent attraction between what for convenience we may call the + and – atoms of *different* molecules, thus weakening the + and – attractions *within* the molecules, by means of some force, motion, or heat. This theory also includes in one the two long-contested theories of dynamic electricity, the Contact and the Chemical, as is explained § 259.

Now, returning to Fig. 12, let the line of dots *c* represent the molecular chain, which is shown variously formed to convey the idea of the different substances which may compose it. If we separate the two surfaces, the intervening air is polarized, and keeps the chain complete. Readers will now see the explanation of the experiments § 24. When we rub the electric the chain is formed through the body. On separation it completes itself through the air, showing the one hand holding the electric +, the other hand –, or the reverse. On presenting the electric, the ball, coming within the circles of polarized molecules, is itself polarized and attracted. It then sets up its own circle of polarity through its suspending fibre, supporting rod, down the stem, and across the air, and hence all the resulting phenomena of attraction and repulsion; for this reason also the results are so different when the suspending fibre is non-conducting or conducting, inasmuch as on that depends the road through which the effort to discharge must be made.

32. The foregoing remarks show the new meanings which, in accordance with this theory, must be given to the old terms of tension and discharge. Polarization already bears this meaning, though it has also been applied to some other phenomena. But though "discharge" is described as the breaking up and re-formation of molecules, it is most probable that it includes another process. This is the simplest to conceive, and is certainly that which occurs whenever chemical action takes place, and probably, therefore, in all passages of electricity through liquids, as explained § 280, on electrolysis. But it is possible that the molecules transmit the motion without being themselves broken up. We do not understand yet what *cohesion* is, but it is certainly an attraction between the molecules, acting from their centres, in a manner analogous to the action of the atoms on each other; hence we may readily perceive the probability of another kind of polarization, consisting of a tendency to form groups of molecules, and to effect discharge through the extra molecular forces of cohesion, instead of through the atomic or chemical attractions *within* the molecules. This subject has not as yet been examined, and indeed the task is a very difficult one, though it will well repay those who have the power to examine it, for here may possibly be found the explanation of the differences of action of electricity on different bodies, and their relative conductivity, as depending upon the forces either of atomic attraction or molecular cohesion, and the energy required to overcome either of these according to circumstances. The same explanations and the same diagrams will however equally convey the idea, whether we consider that Figs. 11 and 12 represent the single molecules breaking up, or groups of molecules doing so, because the figures are not pictures of the things themselves, but merely an endeavour to realize ideas as to their actions.

33. The fundamental laws which experiment has thus far developed are:

(1) *Electrified substances attract neutral substances, and then under certain conditions repel them.* They do so by polarizing their constituent molecules, and then, if the electrified body be in a + condition, attracting the – side of the attracted substance.

(2) *Substances dissimilarly electrified attract each other.* That is, bodies, the external molecules of which present, one their + extremities, the other their – extremities to each other, are mutually attractive.

(3) *Substances similarly electrified repel each other.* That is, there is no attraction between the two molecules presenting their + or − extremities to each other, and they apparently repel each other. (See § 40.)

These are the ordinary electrical laws (for a scientific *law* means the statement of a natural fact), interpreted according to the molecular theory. The old theories assume that a body could be separately charged with + or − electricity. The facts which lead to this supposition are explained by the molecular theory thus: The molecules being polarized and unable to discharge, are for the time fixed with their + or − extremities outwards, and the phenomena called *charge*, which are next to be considered, present themselves at those points of the polarized chain where a change of the nature of the molecules forming the circuit occurs, as at a surface surrounded by air. The molecules of that surface appear to form the termination of a conductor, and are called poles, or charged bodies, according to the circumstances. Really they are only points at which the action is manifested, because there it passes from one class of molecules into another class, *and it is only manifested by furnishing it a new molecular path.* They resemble, in fact, the poles or electrodes in a chemical decomposition cell.

So attraction does not take place directly between the electrified and attracted bodies; the electric develops chains of excited molecules, among which the attracted body is suspended. Its molecules take part in the action, but being held together by cohesion, are obliged to move as a whole in the effort to discharge; its motions are thus representative of the invisible molecular motions, and are also a restoration as mechanical motion, of the primary motion, the arrest of which by friction produced the electrical molecular tensions and force.

34. The action of the electrophorus will exhibit many of the principles of electrical science, though we cannot obtain from it any very striking effects like those of powerful machines. A very convenient and simple form consists of a glass and ebonite disc (the glass merely for noting differences of action), provided with a cover like Fig. 6, and a stand of wood, somewhat larger than the disc; this may be made either of one piece, or preferably of two cemented together with resin melted with a little boiled oil; the grains crossing prevent any tendency to warp. The wood should be thoroughly baked, well covered with shellac varnish, and supported by three feet of ebonite rod or guttapercha to form an insulating stand. The upper face should be covered all over with tinfoil, connected to a small hook screwed into one side for attaching chains to. On the edge of the face should be three studs or pieces of wood cemented so as to hold the disc in its place when

rubbed. These stands serve also for many experimental purposes, and may be used as an artificial "earth." To use the apparatus for examining the principles of the electrophorus place the ebonite disc on the insulated stand, rub it well with a silk handkerchief, and apply to its face a *proof plane.* This is simply a miniature cover, a piece of metal or wood covered with foil, and mounted on a glass handle; it is well to have a variety of these of various forms and sizes, providing them all with a piece of tube or a wire at the back, to slip on a glass handle or a stick of shellac. On touching the ebonite with this and presenting it to the pith ball electroscope it will be found that there is no action. Now this may arise from two causes, and therefore the true principle must be explained.

35. It is generally considered that when an insulated body touches a *charged* one, the two become one as far as the electricity is concerned; that this distributes itself over both surfaces, and when these are separated, each is supposed to retain its proportionate share of the "fluid." The proof plane is so employed in many cases, but it acts differently on the electrophorus, a fact which throws great light upon the true but ill-understood nature of "Charge." The electrophorus is apparently, to all intents, a charged body, for its face, if resinous, is in a purely negative or − state, yet if we apply the proof plane and remove it we shall only discover a faint charge by very delicate instruments. To obtain electricity on the plane we must touch its upper face with a conducting body, in what is called "connection to earth"; practically the operator's finger will serve, but for the sake of theory the connection should be a piece of wire attached to a chain, which drops on the floor, or is hung to a gas-pipe. This is also the way in which the electrophorus is used for any purpose; it is excited by friction, the cover placed on its face, touched on the upper surface with the finger, which is then removed; the cover when now raised is found to be charged, and sparks may be drawn from it. The instrument, when excited, will retain its powers for a long time if the cover be placed on it; in a dry air it may retain its charge for days or weeks, ready to give a spark without fresh excitement. But only very moderate effects will be produced with the stand insulated. By dropping a chain from the hook to the floor, a much greater effect is observed, and still more if, while rubbing, this chain be held in the hand or connected to the rubber. We thus carry out the principles of § 18, and facilitate the forming of the polarized circuit, though we may entirely dispense with the "connection to earth" so strongly insisted upon in most electrical works. The cover or proof plane thus applied to an electrophorus is in the opposite electric state to that of the disc itself, or that it

would assume by what is more properly called "Charge" by simple contact.

36. The explanation of these phenomena on the fluid theory is, that we collect free – electricity on the disc, and this attracts the + of the cover towards it and repels the –; if we simply remove the cover these re-combine, and no free electricity remains upon the cover; if we touch the cover the – electricity on the upper part escapes, and thus when the cover is raised it remains charged with +. This explanation is delightfully simple, if we ignore the fundamental absurdities of the fluid theory itself, already pointed out, as well as the special difficulties of the case, such as that when the – electricity has gone to earth, there is nothing to prevent the – of the disc uniting with the + of the cover and dividing their united selves between the relative bodies, instead of undergoing forcible separation when the cover is lifted. Still, there is an apparent simplicity in the doctrine, which explains its acceptance at a time when little or nothing was known of the molecular constitution of matter, and the atomic theory of chemistry had not yet been conceived.

37. The molecular explanation now to be considered has the disadvantage of requiring some knowledge to understand it, and therefore will not commend itself to those who have not fully digested the ideas as to the constitution of matter presented in §§ 2–13. The friction polarizes the surface molecules, and these their neighbours below in one direction, and the rubber, and body of the operator, in the other; afterwards the face of the disc and the stand establish circles of molecules polarized, but to a very feeble tension, because they are not limited in number, every molecule dividing its actions among those which come within its spheres of attractions. When the cover or plane is laid on the disc, its molecules form part of these chains, and are polarized, but when removed, they pass out of the lines of action, and therefore show no result, the molecules falling back into their ordinary condition; but if touched with a conductor connected to the back of the disc, the whole action takes place in that conductor, and the conditions of discharge are present except in the substance of the disc itself; the breaking of this chain suddenly while in a state of tension prevents the molecules of the plane from returning to their normal condition when it is removed from the disc; they still are under a strain which compels them either to remain locked, as it were, with their + or – ends all outwards and under the induction of the surrounding surfaces, all in connection with the source of the excitement, or else to form new circles for themselves. Under either condition they must present the appearance of being independently charged and fresh sources of action; and as their molecules would be so arranged during the first part of the process as

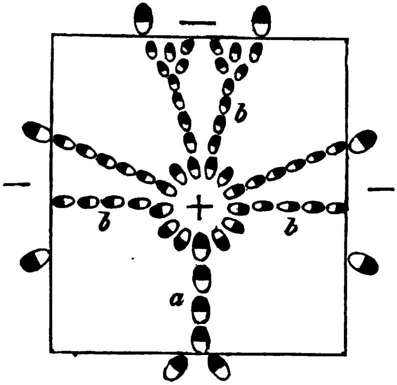
to tend to union with those of the disc, it is evident that in the subsequent stages their polarity, and hence their electrical reactions, would necessarily be the opposite of those of the disc itself.

38. It should be noticed that an excited electrophorus does not itself present the ordinary signs of excitement; a single stroke upon a piece of ebonite with silk or flannel will so excite it, that when presented to a well-insulated pith ball this will be attracted and then repelled with great violence, but if the electrophorus disc be presented after sharp friction, it has only a feeble attractive power; owing to the wide circles through which the polarity is transmitted, and the consequent low tension of all the molecules, together with the great resistance to discharge of the materials of the electrophorus itself.

39. In working for discovery it is requisite to experiment first and then seek the interpretation, and this is a good mode of instruction also; but, on the other hand, an experiment, and, still more, a description of one, is far more intelligently studied when its object is understood; and for this reason, before proceeding to the details of the laws and experiments of charge, it may be well to first explain the general principles, although to understand them fully requires acquaintance with the details which will follow. The expressions of most electrical writers are such as to justify the common notion that either positive or negative electricity is capable of separate existence, isolated from, and independent of, its opposite. Yet all admit this general law, (4) *One electricity can never be produced without producing at the same time an equal quantity of the other.* Thus, in friction, if the electric be +, the rubber is −; so also in a battery, one extremity is +, the other −; and in a Leyden jar if the inner coating is positive, the outer is negative. All theories include this law, because it is a simple fact; but it is an inevitable consequence of the molecular theory, for the molecules necessarily have two opposite sides, and the reactions of these sides are the causes of the phenomena. But the fluid theories assume that, having produced separation of the two electricities, one of them may be dismissed into the earth as the common reservoir, or infinite conducting surface, leaving the other free and isolated. This assumption is attended with many difficulties, all of which the molecular theory disposes of by doing away altogether with the supposed function of the earth, which really acts simply as any other conductor does in dynamic electricity, and has nothing at all to do with static electricity.

When we work an electrical machine, we must lead a chain from the rubber to the floor or gas-pipe, or else we can obtain only a very slight effect. Hence the idea that we make a connection with the mass or surface of the earth itself. But what we really do is to form a connection, by means of moderately good conductors, with *the walls of the room.* The effect is to produce a large surface polarized under feeble tension, and then the whole of the air in the room is polarized and completes the electrical circle. The room becomes, in fact, a large Leyden jar, of which the dielectric *air* represents the glass. The charged bodies or prime conductor is the inner coating, and the walls of the room the outer coating. Thus, when another insulated body touches the first, it does not, as generally supposed, take part of its free electricity. It simply enlarges the "inner coating," and, of course, in doing so proportionately lowers the tension of the polarization of the surfaces. Fig. 13 represents this. + is the charged body, with all its molecules presenting their + extremities outwards: *a* is the earth connection conveying the polarization to the walls of the room, which are thus rendered −, and *b b* are the molecules of air completing the chains. This explains why anyone at all near an electrical machine in action experiences a peculiar tingling sensation. His body is in the path of polarization, and as he is a better conductor than the air, a good part of the circuit is concentrated in his body. All the small superficial hairs rise and point on one side to the nearest wall or other bodies, and on the other with still greater intensity to the machine. This happens if he is insulated, but if he is in some degree of electrical connection with the walls and floor, the nearer he stands to the machine the more he represents the outer coating. He is, in fact, electrified, not, as might be supposed, by the machine and with the electricity of the conductor, but with the opposite, because he completes the polarized chain, while, if insulated, he will be + on one side and − on the other.

FIG. 13.

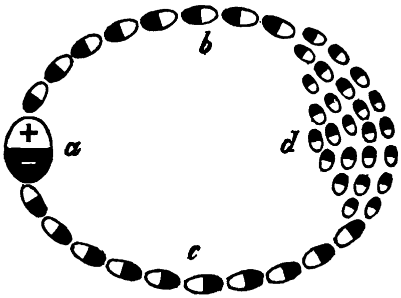


40. At this stage it is proper to remark that, without absolutely denying the existence of electrical repulsion, the experiments on which that doctrine is based are mostly illusory. Thus, with the common experiment, the head of hair, the hairs set as far as possible from each other truly, and hence it is universally stated that they do so because, being all charged with the same electricity, they repel each other; but the fact is, they are simply molecular chains

attracted by the walls of the room, and by tending to them they assume the appearance of mutual repulsion; but if we hold our hand towards the head, the hairs at once all tend to it. It is true they still retain curved forms, which appear to result from repulsion among themselves, but really those curves are just the figures which the laws of resolution of forces require to result from the separate attractions of the hand and the walls. So also with the pith ball; it hangs perpendicular when charged, because it is attracted all round nearly equally. If we approach to it the excited electric, or another body charged with the same electricity, it is repelled, at least, apparently. But, really, we neutralize all the attractions acting on it from one point, the new body absorbing them, while the others are in full action, or even intensified by the increased polarities, and of necessity the ball goes off in the direction of the remaining attractions: so two balls repel each other by absorbing the attractions on one side. And so in other cases, the apparent repulsion is due to the weakening of resistance to another attraction; the case is analogous to that of a counter-weighted body held down to the earth by a string; if we cut the string up flies the body, but not, surely, from any repulsion between it and the earth. It is the superior attraction of the earth for the counter weight which causes the apparent rise and repulsion, these being really a descent and attraction.

41. INDUCTION.—This term is so frequently employed in electricity that it is necessary to define fully the idea it is intended to convey. Generally it may be said, that any molecule when "polarized" *induces* all others within its influences to follow its example, that is to say, employing the true meaning of the word, it *draws them* into the same systematic order: in like manner a magnet *induces* magnetism in neighbouring bodies susceptible of becoming magnetic, and an electric current *induces* a current in neighbouring conductors. This power results from the constitution of the molecule, as defined § 29, when under the influence of "polarization," which directs a portion of its constituent energy externally.

FIG. 14.



In Fig. 14 *a* is the primary molecule, the point of origin of the polarizing force acting in both directions and on each side, *inducing* its neighbour to turn towards it that side for which it has the greater attraction. Thus its + side acts on the molecules *b* and its − on molecules *c*, seeking on each side the most rapid and shortest course to complete its chain. The collection of molecules *d* represents the passage from a good conductor into a dielectric, as from a charged surface into air, where the energy or tension is distributed over a number of chains.

42. ELECTRICAL MACHINES.—Static electrical machines may be divided into two distinct classes.

(1) Frictional machines, in which the electric is constantly excited by friction and as constantly discharged into a reservoir of force; this class includes the plate and cylinder machines.

(2) Induction machines which operate on the principles of the electrophorus. The electric is excited by friction at the commencement of operations, but is not itself discharged; there is no continued friction, or only sufficient to sustain the charge, but successive actions of inductive charge, and discharge into a reservoir are effected.

The principles of the frictional machine are those laid down § 18. There is (1) The electric to be excited, the plate or cylinder. (2) The exciter or rubber. (3) The mechanical motion generating friction. (4) The circuit of polarization, which here includes the "separation," because part of it must be non-conducting. (5) The reservoir of force—the prime conductor, as it is called, but which is strictly a part of the circuit of polarization, though most conveniently considered separately.

I. *The Electric.*—This is usually glass, in which case the charge from it is positive; but it may be any solid dielectric, and the first machines were globes of sulphur. Guttapercha may be used, and has been employed in the form of a band stretched between pulleys: electrical machines have been thus generated unintentionally in manufactories where guttapercha belting is employed, and some fires have been caused by sparks given off from such belts running over wooden pulleys. The best electric of all is ebonite, but it has a serious economic objection, as its surface roughens and deteriorates after continued friction. It is subject also to the formation of a film of sulphuric acid upon its surface, owing to the action of the ozone which is produced when the machine is worked, and which is the cause of the peculiar smell perceived: for this reason it is desirable to coat with shellac all exposed ebonite surfaces not to be exposed to friction. Glass is, however, the electric usually employed, because it is cheap and enduring; it has, however, the great drawback of condensing moisture on its surface; as to which see § 20.

The quality of the glass is of some moment, the hardest, containing most silica, is best, hence crown glass, such as window sheets are made of, or that from which common pale green coloured bottles are made, is better than flint-glass or crystal. A cylinder machine may be made of a large bottle, if one is selected with straight sides and polished surface; the latter is important, as a rough surface does not generate electricity well, as only the salient points come in contact with the rubber. There is also a difference of electromotive power between smooth and rough glass; if the two are rubbed together and tested, the smooth is found to be positive, and this agrees with Coulomb's deductions before mentioned, because the particles of the rough surface must be most disturbed.

II. *The Exciter or Rubber.*—This part of the instrument being treated as a very subordinate matter, is seldom made upon true principles. It should present as large a surface as possible to the electric; in a cylinder it should reach within an inch of the ends, and in a plate machine to a moderate distance from the axis, so as to utilize the surface as much as possible; it is best made of a tough but soft leather, well stuffed with the best horsehair to give a firm and even but elastic pressure on the surface; it should be insulated carefully, but be itself conducting, and provided with the means of connection "to earth" or to apparatus. These principles can be carried out thus. The back of the pad should be metal, provided with a stout wire for a connection, and a few fine wires may be mixed with the horsehair stuffing; the leather covering can be secured to the metal back, and then this back may be cemented to and buried in a piece of stout sheet guttapercha or ebonite, by which the pad can be secured to, but insulated from, its supports, which should be provided with screws to regulate the pressure of the rubbers. The face of the rubber is covered with amalgam, and on the edge from which the motion approaches the rubber a slip of stout tinfoil should fold over slightly to make a connection between the amalgamated face and the metal back or conductor, and from the same edge should fold over a piece of soft silk, forming the real face through which the amalgam finds its way, and acts much better than when it is freely in contact with the glass. From the other edge of the rubber extends the flap, which covers the surface of the glass where excited, and reaches close to the points which take the electricity to the prime conductor. It should be made of good stout black silk, sewed to the edge of the pad so as to touch the glass directly it leaves the pad, and outside the black silk should be another, slightly smaller, of oil silk. In a cylinder machine this flap is simply a straight piece lying on the glass, but in a plate machine it is cut to the shape of the disc.

III. *The Mechanical Motion.*—This includes the mounting from which the motion is to be imparted. Either plate or cylinder is to be firmly mounted on an axis; for small machines this may be of hard wood, thoroughly baked and saturated with paraffin; in larger instruments this axle must be of metal, in which case it must be carefully insulated in every possible way. The best way of securing a plate to its axle is to have two loose collars of prepared wood fitting tightly on the axle, and thick enough to take firm hold of it; the plate is fixed between these, and all the surfaces being well supplied with shellac varnish, all the parts are compressed together till thoroughly set and then covered over with several coats of varnish. The supports may be made of baked wood, mortised in the stand. Usually in plate machines this is little attended to, as the pads are often fixed to them, and they provide an imperfect connection to earth through the wood, but in this case only one electricity can be utilized, while by carefully insulating the rubbers we can use either; therefore if wood is used it should be made as non-conducting as possible, and the holes through which the axis is to work may be bushed with pieces of stout glass tube, the bearings being in loose pieces of wood screwed to the sides of the supporting frame; an ordinary winch handle gives the motion, that part of it which is grasped by the hand being a stout glass tube free to revolve over the handle.

IV. *The Circuit of Polarization.*—This, starting from the two faces of the rubbers and electric, is carried by the motion which thus produces the "separation" under the points of the prime conductor, then, crossing the narrow stratum of air in the form of small sparks or a constant luminosity, to the surface of the conductor; thence across the dielectric, the air of the room, to the walls, where it meets the corresponding action which, starting from the rubbers through the earth chain or connections, such as the table, polarizes in the opposite direction the surface of the walls. In charging a Leyden jar or other apparatus, part or all of the action is concentrated there, the two coatings forming the circuit with the material of the jar between them instead of the air.

V. *The Prime Conductor.*—This is the reservoir of force; on its size depends the nature and length of the spark. It usually consists of a large brass tube, and is a somewhat elaborate and expensive affair. This is by no means necessary when we rightly understand its objects; all that is really essential to it is the collecting portion; this is simply a coarse comb or a row of metal points fixed in a rod, and it is well to enclose this in a wooden shield, casing all except the points. The rod is connected to the prime conductor, which may be brass tubing as usual or of wood covered with tinfoil or Dutch metal. It must be carefully insulated or the power will be wasted; its surface must be smooth and brightly polished, and its form must present no sharp edges; all its outlines must be curves as large as possible, and where holes are provided for the insertion of conductors or apparatus, the openings should not be mere holes or tubes, but trumpet-shaped and formed into a curve.

The prime conductor need not be a part of the machine itself; the collecting comb may be connected to a separate collector, as shown in Fig. 14 of the cylinder machine. Dr. Winter of Vienna has devised a peculiar addition to the machine; it consists of a ring of iron rod a foot or so in diameter, mounted on a brass stem which may be inserted into a hole in the prime conductor, which in his instruments is simply a ball: the wire ring is enclosed in a ring of wood made in halves and cemented together and polished. It is stated that a machine giving 7-inch sparks gave 20-inch sparks when this was added.

Mr. S. Roberts has stated in the 'Philosophical Magazine' for January, 1874, that effects of a similar character (that is long and vivid sparks) are obtained by substituting for the prime conductor a long Leyden jar made of a piece of narrow glass tubing.

43. It may be as well to mention here, that though brass chains are very commonly employed for connections, they are very bad for the purpose, for they are full of breaks and points; and if the machine to which they are connected is worked in the dark, a constant stream of fire will be seen passing from them; it is much better to use wire cord, such as is made for sash lines or hanging pictures, and to slip even this within a small caoutchouc tube: chains may be used to connect the rubbers to "earth" or surrounding objects, as there is little tendency to escape unless brought near the prime conductor or plate.

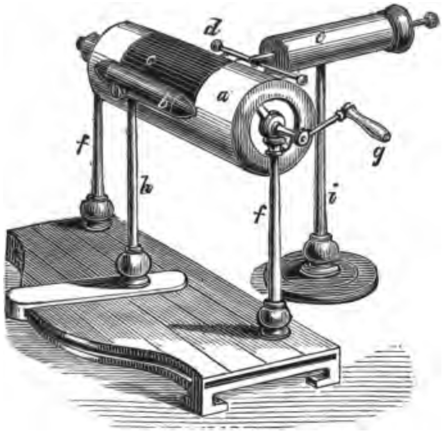
44. **Amalgam** is necessary to develop electricity freely, but its mode of action is not well ascertained; the molecular theory throws some light upon it, for it is a mixture of good and bad conducting substances in such condition that the molecules are readily capable of motion, hence they are easily polarized and communicate that polarization to the electric: it is probable also that a very fine and discontinuous coating is given to the electric which facilitates the collection of the electricity by the points. There are various formulæ given, but it is uncertain if any one has a special advantage. Some of them are as follows:

Zinc	5	11	2
Tin	3	24	1
Mercury	9	65	6

The best process of making is to melt the tin and zinc together in a porcelain crucible over a Bunsen's burner, then stir them well together till they are just about to solidify, when the mercury should be added, worked in, and the whole transferred to a small mortar made warm enough to soften the amalgam while it is well worked together, after which a portion of hard tallow not quite equal in bulk to the amalgam is to be worked in.

45. The foregoing principles being understood, those who wish to construct instruments for themselves may easily devise arrangements to suit their means. Fig. 15 shows an ordinary form of the cylinder machine, and Fig. 16 of the plate machine, the lettering on both is the same for corresponding parts: *a* is the electric; *b* the rubber; *c* the projecting flap; *d* the collecting points, shown only on one side of the plate machine, but which should also be presented to the other face; *e* is the prime conductor; *f f* are the supporting frame of glass, ebonite, or baked wood.

FIG. 15.

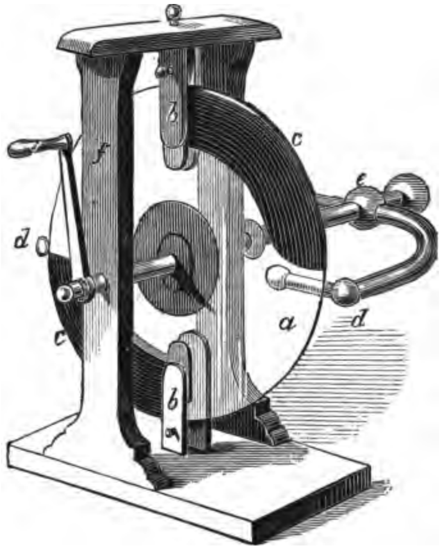


Very simple materials may be used, thus insulating supports, or handles may be made from ordinary phials, the object to be supported being cemented into the neck with a mixture of about equal bulks of powdered resin and well-dried Bath brick melted together with a very little boiled oil.

As the working of machines is so greatly affected by damp, they may with advantage be built up within a closed box lined with ebonite instead of upon a frame, the axis passing through a stuffing box so as to exclude the external air, while the interior might be kept dry by means of a drawer containing lumps of fused chloride of calcium; in this case one side of the case might be made a condenser replacing the usual conductors.

46. The second great division of electrical machines is based upon the principle of the electrophorus; there is not a constant

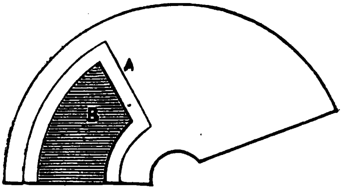
FIG. 16.



friction, but a small charge is given to a piece of ebonite, and a revolving disc plays the part of the cover, taking a succession of charges, and transferring them to a condenser or conductor which in turn reacts upon the original charge and gradually raises it to a high tension. In these instruments, although there is no direct friction, there is set up a resistance to motion by these electrical actions, which acts the part of friction and transforms the mechanical energy of the motion into electrical energy with all its effects.

There are several forms devised by various electricians, but the only one of general interest is the Holtz machine, which has undergone a series of modifications at the hands of Poggendorf and Professor Morton, and Mr. Ritchie in America. The earlier form will be found illustrated in several of the later electrical books. It consists of two thin flat discs of glass: one of these is fixed upright by being held in four clips carried upon glass bars between the front and back pair of standards; this disc has a hole in its centre to allow an axis to work freely in it: upon the horizontal diameter are two segmental openings or windows, upon the edges of which on the outer face of the disc are pasted segments of paper with tongues projecting into the opening. A somewhat smaller disc rotates at about one-eighth inch distance. Beyond the farther side of this disc are two collectors or combs, such as are used in the ordinary electric machine, facing the points of paper, so that the rotating disc moves between the paper and collecting points. The combs are fixed upon horizontal rods which pass through the bar which carries one end of the axis, and these rods terminate on the exterior in metal balls, in which work rods exactly like the arms of an ordinary universal discharger, which control the distance between the ends, they being the positive and negative terminals of the machine; the effect is greatly increased by attaching to each of the combs or connecting rods the interior coating of a small Leyden jar, both outer coatings being connected together. Mr. Ritchie simplifies the fixed disc by cutting it across two diameters so as to cut out of the opposite halves about one-third of the quadrant in place of the original windows; he also extends the paper armature so as nearly to fill up the quadrant. Mr. Van Brunt has carried this alteration farther by substituting tinfoil for the paper, but pasting down a rim of paper around the edges; for the points he uses a row of half-inch pins mounted as they are usually sold, glueing them down on the glass by means of the paper with a strip of card under their heads, so as to cast the points just over the thickness of the glass in the opening, the tinfoil being then laid on in contact with the heads, and then the paper edging before mentioned which is varnished when thoroughly dry. Fig. 17 shows a half disc on this last plan.

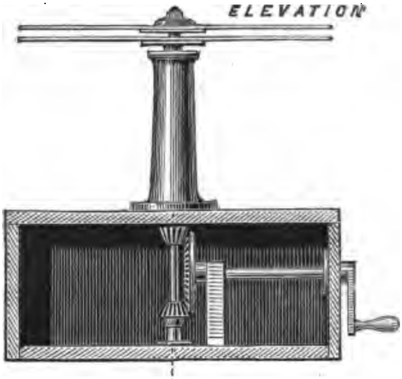
Fig. 17.



To work the Holtz the two arms are brought in contact; a piece of ebonite is rubbed and laid on one of the paper armatures. The disc is then rotated and the arms gradually separated. If the motion is arrested, or if the arms are separated beyond the distance at which sparks can pass, the machine loses its charge and the process must be recommenced. To charge Leyden jars, &c., the two arms are connected to the two coatings.

In the more recent forms of the instrument, the fixed disc and its openings and armatures are dispensed with, and two plain discs are employed, both revolving, but in opposite directions. They are usually placed horizontally in this form, the upper is fixed in the middle of an axis which is mounted in a frame; the lower is mounted upon a shorter hollow axis which runs upon the other, as in the train which carries the hands of a clock. Each axis has a small pulley fixed upon it, at the top for the upper plate and the bottom for the lower. A fixed axis at a little distance carries a driving wheel with two grooves in its edges, and an endless cord passes round so as to rotate the discs in opposite directions.

Fig. 18.



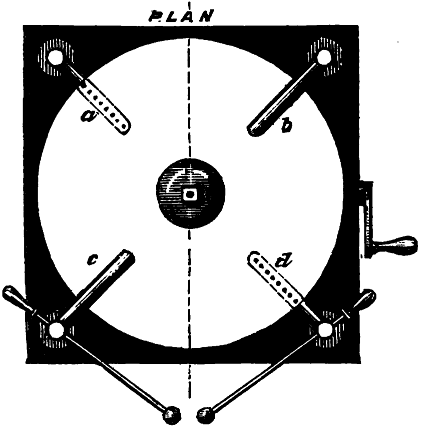


Fig. 19.

Another form of mounting has been suggested by Mr. Turton, a correspondent in the 'English Mechanic,' which is shown in Fig. 18, the plan of which, Fig. 19, also exhibits the usual collecting arrangement.

Four glass or ebonite pillars carry the collecting combs which are connected together in pairs, *a* to *c* and *b* to *d*. Of these pairs one comb is placed under the lower disc and the other above the upper disc with the points nearly in contact with the glass. It is found better to add another collecting comb above the discs facing the lower one *a*. The instrument is excited by holding a piece of rubbed ebonite opposite the points of *d* while rotating the discs.

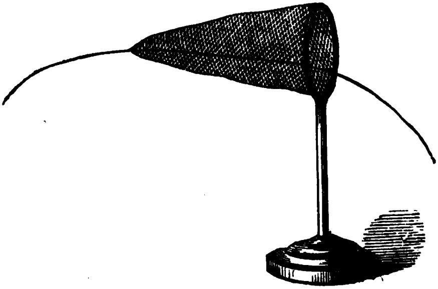
The principle of all the forms is alike. The excited ebonite induces a circuit through the combs and the discs; these latter retain the locked condition of polarization, and when moved under the other pair of combs, in turn set up a fresh circuit: the constant revolution brings new charges, these circuits act and react upon each other, converting the energy applied, until the tension is raised to the desired point; the process of conversion is continued until whatever inductive circuit exists has stored up the full amount of energy its *inductive capacity* enables it to absorb in the condition known as "charge," or under the proper conditions it restores that energy by "discharge," as heat in the form of sparks, as mechanical motion when points are caused to revolve, or in any other of the forms which electrical energy can assume.

In this instrument we see this conversion more plainly than in the ordinary friction machines, because both the poles being insulated and the circuits limited, we are freed from the ignis fatuus of the earth connection: it is obvious that we do not here pump a fluid out of the earth, or run back into the earth any excess fluid which we cannot otherwise dispose of; we are brought face to face with the limited "inductive circuits" in which polarization can be set up, energy then flowing through as electricity equivalent to the mechanical energy absorbed.

47. DISTRIBUTION OF ELECTRICITY.—Most electrical works occupy many pages and numerous illustrations to show the next leading law, (5) *Static electricity is found and exists only on the surfaces of bodies.* Faraday made many beautiful experiments to show this, and to prove, among other things, that the force is to be found only on *external* surfaces. Thus he showed that if a metal sphere have a small opening through which a proof plane can be passed, and it is thus charged from the inside, the electricity at once passes to the exterior, and none can be traced on the inner surface. A consequence of this law is that hollow bodies accumulate as much static electricity as if they were solid, while conduction of current electricity passes through the whole body and depends on its mass. One illustration of the apparent relation of

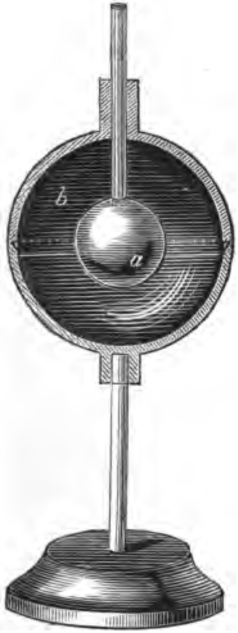
electricity to external surfaces will suffice. Fig. 20 is a conical bag of stiff muslin, provided with silk cords by which it can be turned inside out; it is mounted on a metal ring supported on an insulating stand. If a charged body is introduced into the open mouth and touched to the bag, the electricity leaves it, and is found on the outside, on which all the little fibres will rise; no trace of any is to be found in the interior; if now, by means of the strings, the bag is turned inside out, the electricity at once passes to the other and now outer side. The same principle is illustrated by experiments to be described for other purposes. Faraday even showed that inside an insulated chamber built for the purpose within another room, and strongly charged with electricity, the most delicate instruments contained in it and connected to it showed no trace of action.

FIG. 20.



The two great authorities on electrical distribution and its consequences are Coulomb and Sir William Harris. The first examined the subject in the most elaborate manner, by means of his beautiful torsion electrometer, and arrived at certain conclusions which he embodied in a series of laws. Sir William Harris, on repeating the experiments, found Coulomb's results only approximately correct, and modified these laws accordingly, and to this hour the subject remains in this indefinite state. We are now ready to see the reason for all this. Electricity in its static manifestations *must be found only on surfaces*, where the polarized circuit passes from one body to another; it is a state of strained rest, unmoving tension, and can only be discovered by transferring that state of tension to another body. The laws of distribution and accumulation can only be approximate; they are only general principles, and the distribution will vary with every variation in surrounding bodies, that is to say, with every alteration in the lines of *least inductive resistance*, so the charge will be found only on the external surface of an isolated body, if, as is usually the case, its polar circuit is directed to external bodies; but if an interior body is provided through which the circuit is completed, then electricity is to be found on the inner surface.

FIG. 21.



48. Fig. 21 conveys the facts and the theory: *a* is a ball of metal mounted on a glass tube which is cemented into a neck on *b*, which is a hollow sphere divided in two at its horizontal diameter, so that the upper half may be lifted by the glass tube, which should be longer than it is shown; the lower half is mounted on an insulating stem. If now we connect *b* to the prime conductor in the usual manner, it will receive a charge, and on lifting the upper half no electricity will be found on the inside of *b*, or on the ball *a*. But if we drop a wire through the tube on to *a*, and charge it, connecting *b* to earth, that is to the rubber of the machine, then we shall find + electricity on *a*, and – on the *inside* of *b*, while the outside will show no signs of electricity. If the rubber is as usual connected to earth and also direct to *a*, while *b* is charged +, both inside and outside will be found charged *alike*, and the inner charge will be equal to the – charge found on *a* and its tension greater than that of the outer charge, this being due to the smaller space of air between the *inside* of *b* and *a*, as compared with that between the *outside* of *b* and surrounding bodies; we have in fact here two *inductive circuits*, and the charge will divide itself between them just as a current divides itself between two "derived *conductive* circuits." (§ 238.)

Again, if we charge *a* as before, and then by a discharger connect the wire leading to it with the outside of *b*, on removing the upper part no trace of electricity will be found remaining on *a*, if the rubber is connected to "earth." Further, if we charge *a* from the conductor, the rubber being to earth and *b* not connected to the machine at all, we shall find that its inside is in a – condition and its outside +, and this outer charge will be equal in quantity to that on *a*, and yet although the outside and inside are in intimate metallic connection, these two electricities will not reunite as long as the charge is maintained upon *a*. (See § 56.)

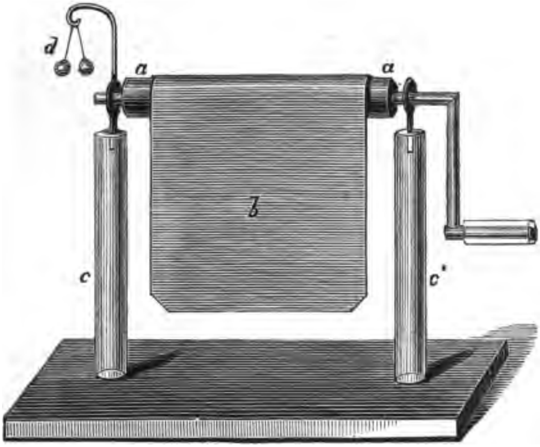
49. Static electricity, then, resides on surfaces; and all other things being alike, the quantity (to use the old inevitable, but misleading term) is, from a given source, in the ratio of the surfaces; this is true only of spheres at some distance from other bodies; with other forms the case is different. A sphere in these conditions may be regarded as a radiant point, which was the old view of electrical action; and thus the actions of spheres when charged vary in the ratio of the squares of the distance as to attraction and repulsion; but this, again, is only when disturbing agents are at a distance. If, then, a ball, say, of 1 inch diameter, be charged to the full extent a given source is capable of, and another ball of the same size be brought in contact with it, and then separated, the first ball will only retain half its electricity; if the second ball be 2 inches in diameter, the first will retain only one-fifth, the other four-fifths passing to the second. This is the consequence simply of the relative surfaces, which increase in the ratio of the squares of the diameters, so that a 2-inch ball has four times the surface of a 1-inch ball. This relates to the "quantity" only, and the reason is evident: the number of molecules of air in contact with the surfaces increases in the same ratio as the surfaces, and hence in that exact ratio increase the separate chains of polarization which can be set up at those surfaces, towards surrounding objects.

50. In ellipses the distribution is different: the electricity is found to be collected at the ends in greater degree than at other parts. The mode of testing is by means of the proof plane and torsion balance (§ 66). On touching a surface with a proof plane, this latter becomes for a time the surface, and removes just the quantity of electricity belonging to the surface it displaces; another mode of trial is by attaching gold leaves or pith balls hanging by linen thread, which is a conductor, to different parts of the cylinder, when they will open differently at different parts. De la Rive says, "A cylinder 2 inches in diameter and 33½ long, terminated by two hemispheres, when touched by the proof plane at the middle or at one extremity, manifests electric reactions, of which the ratio of the first is to the second as 1 is to 2·30. The electric reaction varies but little from the middle of the cylinder to 2 inches from its extremities, and increases from this distance to the very extremity, where it is at its maximum." We may at once see that this statement holds good only for one set of circumstances. The force is manifested at the ends because they give the path of least resistance, and because a greater number of radiating lines can start from them towards surrounding objects (§ 55). But if a wire ending in a large ball be led from the gas-pipe and held

towards the cylinder, the electricity will accumulate mainly towards the spot it approaches. So if two or many spheres are placed in contact in a line, the force will tend to the outer ones, and this furnishes the explanation of the action of points, and also of sharp projecting edges. They are the terminations of good conductors, and on them the action is concentrated, the lines of polarization converging towards them. For similar reasons the effects of charge upon flat surfaces, terminated by edges, cannot be expressed in any definite formulæ, as it is affected both by extent of surface and of lineal boundary as well as by the surrounding bodies.

51. If we take our two balls of 1 and 2 inch diameter and charge them both at the same time from one source, the 2-inch will have four times the "quantity" of electricity on it that the other has; but if we apply the two balls to two exactly similar electroscopes, they will both give exactly the same indications, or if both are tested by proof plane and balance, both will be found charged alike. It is necessary therefore to see what will be the effect of altering the extent of surface without altering the so-called quantity of electricity. We can do this by the instrument shown, Fig. 22: *a* is a brass tube, one end fitted with a piece of metal from which extends a wire for the axis, the other end fitted with a plug of indiarubber, in which is secured a wire forming the other end of the axis, and bent into a winch; *b* is a sheet of tinfoil; *c* and c^1 are glass tubes, to the top of which are cemented wires bent round to serve as bearings

FIG. 22.



for *a*, on *c* is soldered a wire hook to carry two pith balls, or slips of thin foil, or a wire may be led from it to a quadrant or other electrometer; *a* may be wood or glass, if a piece of foil is carried to the axis so as to connect the electrometer, and in this case a more exact measurement of the exposed surface may be obtained. If the foil *b* be now charged in the usual way the electrometer will give an indication representing a given charge. Now wind up the foil, and as the exposed surface diminishes the action is concentrated on that smaller surface, and the electrometer indicates accordingly; when the surface is reduced to half, the instrument indicates twice as much force as before; when it is one-fourth, there is seen to be four times the force—yet in *each case there is the same quantity of electricity.* The property we have now displayed is Intensity, a term which, however, is very confusing, on account of its having been misused; this property is also called depth of electricity by some, more commonly Density, and still more often Tension. It is this condition of the part of the electric inductive circuit in which they are placed that is measured by electrometers, not the *quantity* of electricity.

This has an important bearing in relation to dynamic electricity, in which electrometers are used as well as the more common galvanometers. The grand distinction is this, the galvanometer is affected solely by the current or absolute *quantity* of electrical action passing in a given time; the tensions existing have no effect, and the instrument will give the same reading in any part of the circuit. The electrometer is not affected by quantity, but by *tension* alone, and when applied to a circuit will read differently in different parts, because the tensions vary. (§ 215.)

52. We have now to examine the relation of these two characteristics of electricity, *quantity* and *tension.* Heat furnishes several analogies which, though imperfect, aid the conception. It also has the two properties, quantity and intensity. There may be the same equivalent of heat in a large measure of water at 50° and in a piece of iron at white heat; the quantity of heat would be said to be the same, but the intensity, i. e. the temperature, would be very different in the two cases; so far the analogy with electricity is perfect; but we have a definite idea as to heat being measurable by its *quantity,* which misleads if the same notion is applied to the case of electricity. A moment's thoughtful consideration will show, however, that the idea as to *quantity* of heat is a misconception; our only means of measuring heat (its amount, that is to say) is by ascertaining the quantity of any substance it will raise to a certain intensity or temperature, and this varies with every substance in ratios dependent on the atomic constitution; it is impossible to measure a *quantity* of heat *as heat.* Thus understood, the analogy

with electricity is again perfect; we cannot measure a *quantity* of electricity, we can only measure the degree of tension we can develop in matter; and when dealing with currents, we find that this also varies with the atomic constitution of the various bodies; in static electricity, however, the idea of quantity is a delusion; all we can measure is the degree of tension produced, and for a given amount of energy that must obviously vary with the amount of matter on which it is concentrated; that is to say, if a given amount of energy produces a certain tension on one area, if the area is doubled the tension must be halved, because it is exerted upon double the number of molecular chains terminating on the area or surface.

This inevitable deduction from the theory exactly accords with experiment, and furnishes the reason for the laws which have been deduced from observed facts, and also the means of extending and correcting those laws.

53. On the various theories which suppose electricity to be a fluid, a thing having a real existence of its own, a different explanation is given, which, plausible at first sight, and sufficiently satisfactory as long as we confine it to static electricity, becomes utterly incomprehensible when we apply it to currents, and has thus caused the confusion of mind almost universal on this point. It assumes that this substance, electricity, when freed, is held to surfaces alone by some means, against a constant effort on its own part to escape: if a given quantity is placed on one area, it covers it to a certain depth, collects mainly on points and edges, where in consequence its depth or thickness is greatest; the intensity or tension is the measure of its effort to escape, and depends on the depth or thickness of its stratum, to use language which, though unsuitable to an intangible, almost spiritual essence, is yet the only mode of making the idea intelligible; if the surface be now diminished, as by rolling up the foil in Fig. 22, the electricity accumulates on the diminished surface, and by the time the surface is halved, of course the thickness of the stratum must be doubled. Hence it is explained why the density of a given quantity of electricity varies in the inverse ratio of the surface to which it is attached.

54. It is necessary to give this theory, but it breaks down when we find that the idea of a measurable *quantity* of electricity existing at all is fallacious, nor is it any more comprehensible than the explanation furnished by the molecular theory—that the relation between what is called Quantity and Intensity is simply the number of molecular chains on which energy produces Tension; in static electricity, dependent on the area of the conductors in contact with the dielectric or air; in dynamic electricity, dependent on the molecular constitution or equivalent relations of the substances forming

the conductor and on their sectional area, which it is obvious represents exactly the charged surface in static electricity, where this is viewed as simply a section of the inductive circuit, when it passes from one medium to a different one. As it is an evil to change terms once familiar, the term "quantity" must still be used for this relation of energy to matter, but it cannot be too strongly fixed upon the mind, that this word does not mean a *measure*, or the existence of a thing to be measured, but simply a *number* proportionate to the molecular chains in which is set up the condition illustrated § 29.

55. One of Faraday's beautiful experiments contains the essence of many, and illustrates most of the various points hitherto considered. Let Fig. 23 represent a room containing *s*, a source of electricity, such as a machine, to the prime conductor of which is suspended a ball +, the rubber being connected to earth, that is to the walls; *e* is an electrometer which if connected to + will show positive electricity by the leaves diverging; if instead of this *e* is connected to the walls, a feeble divergence will be manifested, but this time it will show negative electricity; this, however, will require a very delicate instrument, because although exactly the same *quantity* of negative electricity exists on the walls as there is of positive on +, the surface is so vastly larger, that the tension is so low as to render its presence almost undiscoverable. In this figure the radiating lines from the walls indicate the lines of polarization of the molecules of air.

FIG. 23.

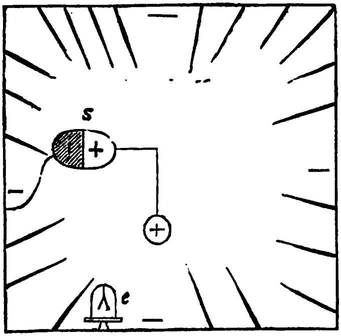
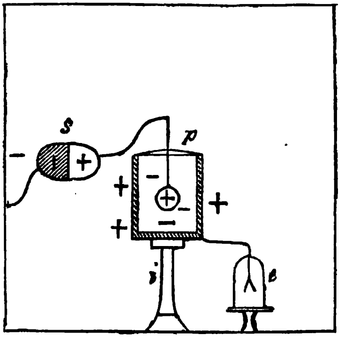


FIG. 24.



56. The experiment is further developed in Fig. 24, in which *p* is a metallic pail surrounding +, and itself insulated by the glass stand *i*. The pail is not in contact with +, yet on connection to the electrometer its outside is found to be +. In fact this experi-

ment is in principle the same as those described § 48, and by calculation of the surfaces, the pail will be found to have the same quantity of positive electricity on its exterior surface as + itself has, yet the latter has lost none; on the other hand, if + be now touched to the pail and discharged, *p* will receive no more electricity, nor will *e* manifest any change in its condition, although + has lost all its charge. The reason is, that the pail when placed round + without contact, takes the place simply of the particles of air, and by presenting thus a change of substances, manifests the condition of polarization existing in the air it displaces, but not manifested or discoverable there, because these effects of static electricity are never exhibited within any single substance forming part of the inductive circuit, but only at the points where that circuit passes from one substance to another, that is to say, at the surfaces in contact. Thus it will be found that the interior of *p* in this condition is in a negative state, and this is usually termed electrification by induction; it is, however, embraced in the general theory that electricity is simply a chain of polarized molecules, and any molecules inserted in the chain necessarily become polarized. Instead of a single pail, several may be employed within, but insulated from each other, when each will show − electricity inside, + outside, and each will be found to have exactly the same quantity, with a tension proportioned to its surface.

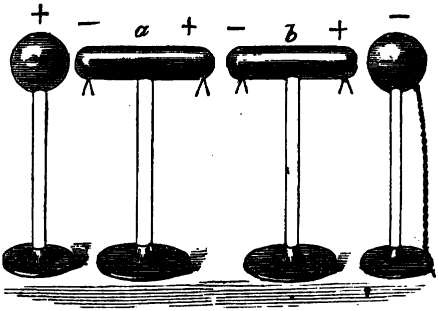
Several important conclusions may be drawn from this experiment. It is a fundamental law that no effect can be produced without a cause, force equivalent to it being expended. But if the charged ball + be inserted into a set of pails, it polarizes them, producing a number of surfaces all charged with as much electricity as itself without itself losing any. Nay, if the ball be first inserted before charging, it will be found that it can be charged more easily than when the surrounding pails are removed. Now if induction were a fresh effort of force, it is clear that neither of these circumstances would occur. Why they do occur is evident on this theory. The resistance to polarization of the metal pails is less than that of the air, they therefore require no effort of force, on the contrary, the transfer of the state of tension from air to metal diminishes the force absorbed in the action, or the inductive resistance of the circuit.

When it is said that the charged body loses no force, the statement requires explanation; it actually loses, but then every charged body does this, and in every experiment the tension is constantly falling at a rate dependent on the state of the air and surrounding objects; what is meant therefore is, that this normal rate of loss is not increased by the condition of the experiment.

57. Exactly the same teaching is derived from the experiment

shown in Fig. 25, which is commonly employed to illustrate "Induction," as though it were an action set up by a body possessed

FIG. 25.

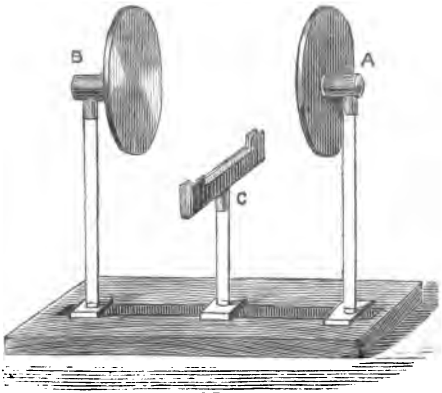


of free charge, while it really exhibits the mode in which the chain of polarization is developed. + is a charged ball on an insulating stand; if we imagine it standing alone, the conditions are those of Fig. 23, an equal quantity of − electricity existing on the walls; we now bring near it, but not near enough for a spark to pass, the insulated cylinder *a*. This furnishes a new path for the force, and its molecules are polarized, gold leaves or tinfoil suspended at its ends will diverge, and by examining their condition the charge at the end nearest + is found to be −, and the other end positive. The common explanation is that the free electricity of the ball decomposes the natural electricity of the cylinder, attracting to its nearest end an equal quantity of the opposite electricity, and repelling the similar to the other end. Add *b*, a similar cylinder, and the same result occurs in it, and in as many as we please. Terminate the series by a ball similar to the first; it, like the cylinders, is polarized; but if by means of a chain or a discharger we connect the ball to "earth" for a moment, we find the ball is then charged with − electricity alone, and to continue the old explanation, its + goes to earth, leaving the free charge opposite to that of the first ball.

But the real explanation is this: When *a* is placed near the ball, it presents a more ready path for the force, because its molecules resist less than those of air, hence a twofold action. Its molecules are polarized by the force charged on the air it displaces, but also a disturbance of the previously-existing arrangements is produced; instead of the polarization proceeding in all directions equally, *a* presents, by its enlarged surface, a much readier path, and the largest portion of the force tends to it, and will result in a spark passing if they approach too closely, while if this is avoided, a simple redistribution of the lines of force occurs. When *b* is added, a similar result and fresh distribution occur; and again when the last ball is presented; but when this last is connected to earth, it becomes the nearest portion of the surrounding surfaces. The force distributed in Fig. 23 over the walls is collected chiefly on it, and nearly the whole is contained in the balls and cylinders, the circuit completing itself through the surrounding air. The whole of the circuit will, however, never be entirely confined thus, because it is wholly a question of relative resistances, and electricity always distributes according to the ratios of the resistance, among *all* the paths open to it; hence, the – charge on the last ball will never be equal to the + on the first, as the old theory would involve; if touched together there always remains a charge on + which is equivalent to the – left on the walls, &c.; so also each successive cylinder will be polarized with diminished force, and will retain on removal a slight positive charge, if the final ball has been connected to earth, because from each of them a fraction of its circuit is completed by the walls instead of through its opposite end to the next cylinder. This also explains the residual charge found in Leyden jars after discharge.

58. The same theory explains the action of charged surfaces, which plays so important a part in electricity in the form of condensers, such as the Leyden jar, and those used in induction coils, and in those vast condensers, submarine cables, in which these effects of charge produce the great retardation in the passage of signals, which long puzzled practical electricians. The instrument shown in Fig. 26 is intended for examining this subject. It consists

Fig. 26.



of a wood or ebonite stand with a groove down its middle, in which can be inserted the stems of the other parts which can then be placed parallel to each other, and at various distances. A and B are glass or ebonite stems carrying metallic discs; C is a similar stem carrying a clip frame, which will support a sheet of glass or other dielectric. Now let A, standing alone on the frame, be charged from the prime conductor, it becomes +, and the walls − as usual, and gold leaves or pith balls attached to A will be repelled on both its faces to an extent dependent on the tension of the charge. Now if B is placed as shown, it will produce no effect on A, but will itself be polarized exactly as were the cylinders in Fig. 25, and in a degree depending on the distances; depending that is upon the area of the inductive circuit or lines of polarization which its surface occupies. If B be now uninsulated by touching it, it will be found to be wholly negative. Thus far we only repeat the conditions of the case described in § 57 and Fig. 25.

If we connect A to the conductor, and B to the rubber, the latter being insulated so as to confine the action to this circuit, when we generate electricity electroscopes fixed to the inner faces will be repelled as usual, but those on the outer faces will be entirely unaffected. In this state we cannot discharge either of the discs by any earth connection, we can only slightly diminish the charge; the reason is that the circuit is concentrated on the two inner faces and the intervening air, and if they are the same size, each face contains equal charge as to both quantity and tension. If we touch A, a derived circuit is set up, and a portion of the positive charge passes to surrounding conductors, and the more distant apart the discs are, the greater this portion will be, because the charge will divide itself in proportion to the resistance of every path open to it. If we next touch B, a similar action occurs; first an amount of force passes away equal to that removed from A, and then a negative charge takes its place; thus, step by step, the charge may be removed.

This experiment furnishes the same explanation as that given in § 47 as to the relation of electricity to surface; it shows also that no really free charge exists anywhere, but that where one state exists on any surface, an exactly equal and opposite state balances it on some other surface to which it is related and connected by a polarized dielectric; it confirms the idea presented, § 40, that repulsion is only apparent because the repelled body simply tends to the opposed surface: no repulsion occurs except in that manner: and then, because the ball, by moving, diminishes the resistance of the circuit of polarization of which it forms part.

59. If A, while at the greatest distance from B, and the latter insulated, be charged to the fullest extent a given source is capable of, an electroscope will show a certain force by its leaves expanding; if B is now connected to earth, the leaves collapse; most text books tell us that the reason is, that the negative electricity developed on B by induction, and set free by the positive going to earth, neutralizes the positive on A, which is thus *bound* or *dissimulated*, renewing the capacity of the surface, which is now capable of receiving a fresh supply of force, until the electrometer again marks a point which cannot be exceeded; now if the plates are approached the same process is repeated, the leaves fall, the force is again dissimulated, and a further charge can be placed on A. Freeing our minds from the ideas of *dissimulation*, the theory gives a clear explanation of these facts. The charge a given circuit can receive from a given source is in the *inverse ratio of the resistance of that circuit*; or, in other words, *proportional to its inductive capacity*, which may be called law (6). In each case the electrometer leaves fall because the resistance of that part of the circuit which they form is relatively increased by the diminution of that of the other parts of the circuit, while the diminution of resistance enables the circuit to bear a higher charge until the point is again reached at which the resistance of the circuits balances the electromotive force of the source.

60. If a sheet of glass be placed upon C, Fig. 26, and the two plates brought into close contact with it, we have the ordinary form of condensing apparatus, and a rough means of ascertaining the relative values of different substances, as to what is called their inductive capacity, a subject of the very greatest practical importance. For use in condensers, and in many electrical apparatus, those substances are best which have the highest inductive capacity, as they accumulate the force in the highest degree. For use as insulators, the lowest inductive capacity should be combined with the highest insulating power, for the two, though alike, are not identical; thus, in telegraph cables, if the insulator have a high inductive capacity, the force is absorbed in producing *charge* instead of *current*, and the rate of signalling is diminished. It is not proposed to go into this subject, or to describe the delicate processes of measurement; but the apparatus measures this property by employing sheets of the different materials all of the same exact thickness, and ascertaining the charge a given source can give in each case.

Faraday and others have tested various substances, and the following table from Clark and Sabine shows the relative values as compared with air.

TABLE I.—INDUCTIVE CAPACITY.

Insulator.	Air = 1.	Electrostatic Capacity of a plate 1 square foot $\frac{1}{1000}$th inch thick.
		microfarads.
Air, and all dry gases	1·	0·0323
Resin	1·77	0·0572
Pitch	1·80	0·0581
Bees'-wax	1·86	0·0601
Glass	1·90	0·0614
Sulphur	1·93	0·0623
Shellac	1·95	0·0630
Caoutchouc	2·8	0·0904
Guttapercha	4·2	0·1357
Mica	5·	0·1620

61. Condensers built up in a series of flat plates are now generally used for the same purposes for which the Leyden jar was formerly employed, and as they have many uses their capacity is given in the last column of the table in definite measure, for which see § 206. Unfortunately the list does not give the value of the most convenient of the insulators, paraffin.

The best mode of constructing a condenser is to cut up the tinfoil into sheets of the size desired, and to make of them two piles like the leaves of a book, the one which will represent the outer coating of a jar containing one sheet more than the other, which represents the inner coating; upon the extreme end of each of these piles place a tinned wire or strip of metal, and by means of a soldering iron run all the edges together so as to make a perfect metallic connection.* Cut sheets of paper large enough to allow a margin of at least an inch round three sides of the foil. The paper should be thin, not highly glazed, and should show no acid reaction by reddening when moistened with a neutral solution of litmus, it should be baked thoroughly dry, placed in a vessel of paraffin kept well over its melting point, and then drained sheet by sheet as smoothly as possible. A well-baked piece of wood of the same size or larger than the paper is laid upon a table, its face soaked with paraffin and a sheet or two of the paper laid upon it; upon this is laid the "outer" pile of foil with its soldered end somewhat projecting, and all its leaves turned back except the lowest one which is to be rubbed smoothly out on the paper; lay over this two sheets of the paper, and on the top of this the other book of foil, so placed that it lies exactly over the first sheet excepting for the margins at the opposite ends; turn back as with the other all its leaves except the first, and upon this place two sheets of paper; continue this process, laying back upon the paper, sheets of foil from the books alternately, and between each foil two sheets of paper; when the whole are in place, cover with two or three sheets of paper and a board like the first, the whole should then be compressed by clamps or by screws passing through the two boards, and warmed up to the melting point of paraffin, increasing the pressure to drive out all excess. The first board should be provided with a binding screw at each end, and the wire of the corresponding set of foils soldered to it. It is desirable to keep a delicate galvanometer and a battery in circuit through these screws, so that if by any accident or defect a contact or circuit is completed during the process, the galvanometer will at once show it. Paper thoroughly dried and coated with or dipped into thin shellac varnish, § 20, and dried, may be used instead of the paraffined paper or thin sheets of ebonite, guttapercha, or mica. It is exceedingly difficult to prepare a condenser which will not lose its charge.

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* These books of tinfoil should be well baked and warmed when about to be used, to drive off all moisture from the surfaces of the metal, and it is well to rub each leaf as it is laid down with a dry warm cloth, and the same with the prepared paper, unless used immediately after preparation.

The capacity of the condenser depends (1) upon the specific inductive capacity of the insulating material; (2), upon the area of insulator enclosed between the tinfoil. It is usually reckoned by the area of the foil itself, not including the connecting margins, which do not face the opposite foil, nor one of the outer leaves, because it is not really the foil which is to be considered, but the dielectric enclosed between two connecting foils connected to the opposite poles of the exciting source.

The law is that the capacity is in the inverse ratio of the resistance; it is increased therefore by increasing the area of the dielectric, or by diminishing its thickness; but this latter must be fully equal to resisting discharge, so that the thickness of the dielectric must be increased when a condenser is required to bear charges of high tension, or else the condenser would be destroyed by being pierced, as happens occasionally with the glass of Leyden jars.

62. **The Leyden Jar.**—This instrument, accidentally invented without any knowledge of the principles it is dependent on, is nothing but a form of the instrument Fig. 26, a dielectric with two surfaces connected with the opposite poles of a source of electricity. The dielectric is the essential element, the surfaces form the connections, and hence when a jar is charged the metallic surfaces may be removed, and will be found to be free of any electrical excitement, which will on the other hand be manifested by fresh metallic surfaces applied to the dielectric, the molecules of which are not restored to their state of equilibrium until a

discharge of the force charged on them occurs, either suddenly or by gradual diffusion.

The Leyden jar is so well known, that it is needless to occupy space with either figure or description; indeed it is an instrument that, now its principles are understood, must soon pass out of use, because it is expensive and inconvenient as compared with other forms which effect the same purpose, such as the condensers just described, which may be used as the jar is; if they are made up in sets of a few sheets, each representing a jar, they may be combined for "quantity" as one, or for tension in series, just as jars are; a set of sheets of glass coated on each side may also be used and mounted in a grooved frame; they occupy little space compared with jars, while they can be combined as required by means of balls connected to the surface like those of jars.

63. On bringing a conductor in contact with one of the coatings or terminators of a jar or other condenser into the neighbourhood of the other, a spark passes, which is the discharge of the condenser, and this spark again illustrates the nature of "quantity" and tension. The quantity depends on the surface of the condenser and the tension of the source, and it governs the size or body of the spark, but the length of the spark or the striking distance depends only on the tension. If two condensers made exactly alike as to the dielectric, one of one square inch, and the other a square foot, be both fully charged from the same source, they will have the same tension, but the second will have 144 times the "quantity;" if discharged across a measured space, the discharges occur from both at exactly the same distance, but the size of the sparks will be very different.

64. If a Leyden jar, well insulated, be presented to the prime conductor of a machine, only one or two sparks will pass to the knob connected with its interior, but if a conductor connected to earth touches its exterior coating, a series of sparks will pass; the jar will then become charged, to a point at which no further sparks will pass. These circumstances are analogous to those discussed in § 59, though they are commonly explained as due to electricity becoming dissimulated; it is evident that so long as the jar is insulated no circuit can be formed through it, but its knob simply takes a charge from, and becomes part of the prime conductor; but when the outer coating is connected either directly to the rubber, or indirectly to it through the supposed earth connection, the force is stored up by inducing the state of polarization in the glass or other dielectric.

65. The Unit Jar.—For many purposes it is essential to know exactly the amount of energy which is employed in producing a charge. Fig. 27 shows an instrument for this purpose called a unit

jar. *j* is a small Leyden jar with a covered surface of say 6 inches; the inside is connected to a metallic stem which can either be inserted in the prime conductor or mounted on an insulating stand; to it is also connected a stem *c* terminating in a ball; the outer coating has a ball *a* which is connected to the jar or battery to be charged, it is also provided with two metal rings which carry a screw stem *b* ending in balls; by it the distance separating the discharging balls of the two coatings is regulated, and consequently the tension to which the jar can be charged; *d* is an advantageous addition to the ordinary form, to prevent the irregularity attendant on the moisture of the air, it is simply a cylinder of glass closed at the two ends with indiarubber through which the stems of the two balls pass; a lump of chloride of calcium placed inside will keep the air dry.

Fig. 27.

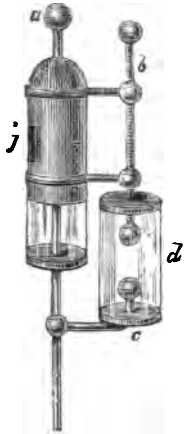
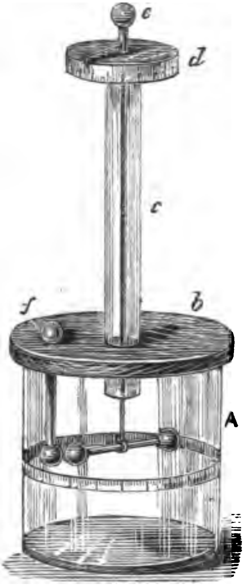


Fig. 28.



As soon as the charge rises to the tension corresponding to the distance separating the two balls, a spark passes and discharges the unit jar without affecting the battery or large condenser, and by counting the number of sparks which thus pass, during the process of charging, the amount of force it has received is pretty accurately measured, because each spark implies a constant quantity and tension. Of course, a unit of this kind can also be constructed of paper, &c., and be thus made of exactly the same specific resistance as the condenser with which it is to be worked.

66. Coulomb's Torsion Electrometer.—This is the most delicate instrument known for measuring attraction and repulsion, and by its means their laws have been measured. Fig. 28, A is a glass cylinder, round which is fixed a circle graduated to degrees; *b* is a cover of baked wood or ebonite, in which is cemented *c*, a glass tube terminating in a cover *d*, also graduated; *e* is a ball fitted

with a pointer, and from it is suspended by a silk fibre or very fine wire a stem of shellac ending in a ball which is gilt; *f* is a ball and stem of insulating material terminating in a gilt ball of exactly the same size as the one on the suspended needle; this passes through a hole in the cover, large enough to allow it to pass without contact.

67. The mode of using this instrument is to charge the ball on *f* from the body whose condition is to be examined; when inserted into its place it touches the other ball, divides its charge equally with it, and then repels it. The force of this repulsion is measured by the torsion of the suspending fibre, for any force producing torsion is proportional to the angle of torsion. To ascertain this angle the balls are so arranged that the movable one is opposite O, on the scale of degrees, as also is the pointer on the upper scale; after repulsion the ball has to be brought to a fixed distance by twisting the fibre. Suppose the angle of repulsion be 36°, and it is required to reduce it to 18°, and that the upper pointer has to traverse 126° to effect this, $126 + 18 = 144°$ is the angle of torsion, and gives the measure of the charge in the terms of this particular instrument. To measure attraction, a stem of insulating material has to be passed through the cover, after the ball on the needle has been moved back, so that this rests against it when attracted, and then the force of torsion required to increase the distance is ascertained as before.

68. A precisely similar instrument is employed in measuring the attractions and repulsions of magnets; for this purpose a magnet is suspended in a stirrup of paper attached to the suspending fibre or wire in place of the stick and balls shown, and a magnetic pole presented in place of the charged ball.

69. Sir W. Harris devised another apparatus which is an ordinary balance, one of the pans of which is a disc, below which is an insulated disc of the same size which is charged from the prime conductor, and the attractive force at varying distances may be thus weighed.

70. LAWS OF ATTRACTION AND REPULSION.—It has been found that both these effects obey the same laws, and are alike affected by distance of the surfaces and quantity of charge.

Distance.—Taking the same figures as in § 67 where 18° required 144 of torsion force, if the balls be approached to 9 the upper point will move through 567°, and this + 9° is a force of 576. We have thus three distances to compare, 36°, 18°, 9°, which are in the ratios of 1, $\frac{1}{2}$, $\frac{1}{4}$; but the corresponding forces are 36, 144, 576, the ratios of which are 1, 4, 16. Hence we have law (7). The repulsive force between two bodies similarly electrified varies *inversely as the square of the distance.*

Quantity.—If the fixed ball be removed and touched with a similar insulated ball its charge will be again divided, and will then be only half that of the movable ball. On replacing it, it will be found that the repulsive forces are only half what they were before, and if the process be again repeated, the repulsion is only one-eighth, hence law (8). At equal distances, the repulsion between two similarly electrified bodies varies *as the product of the quantities of their charges.*

Tension.—Although the foregoing law is based on quantity, it is really to the tension that the effect is due, but as the experiments are based upon equal and similar surfaces, the quantity is proportionate to the tension. Thus, if a pith ball be suspended from two surfaces, one double the area of the other, but both charged with the same quantity, that is, the smaller having double the tension of the larger, the repulsion force manifested by the ball will on the small surface be double that on the larger.

71. These laws, useful in order to fix general principles in the mind, are, however, misleading when baldly stated as definite truths. So far as they are true they are merely consequences of the general principles of the inductive circuit.

When two equal surfaces are equally charged with opposite electricities, they attract each other with a force, as stated, proportioned to the product of the two quantities. Exactly the same result is obtained by a different expression; the product of two equal figures is the same thing as the square of one of them; and from this fact has grown up a pseudo law that the force of electricity varies as the square of its quantity, and much which passes for electrical truth is based on this mode of expressing the law, which is usually adopted by mathematical writers. But when we clearly realize that electricity never does, and by no possibility ever can, reside alone on one surface, we see at once how apt this supposed law is to mislead.

Supposing the instrument Fig. 22, § 51, to present an external surface of 1 square foot, and to be charged by four successive charges of a unit jar of 6 square inches, it would have on it 4 units of force at 1 unit of tension, as + electricity, and the surrounding walls would have 4 units of −, the product being 16, according to the true law; according to the false law, derived from it, $4^2 = 16$ also. When the surface is reduced to half, the tension on that half is doubled, therefore we have surface 2 units, tension 2 units; still 4 units quantity, or total force on the surface, which again, by both laws, gives 16 for the total force of the circuit, because that on the walls is unchanged. So when the surface is reduced one quarter or 1 unit, the tension becomes 4, giving us exactly the same force in a different state of distribution at one of the poles of the circuit.

Of course, in this illustration, we leave out of view the inevitable loss or leakage which, like friction in mechanics, always attends practical operations, but which can be calculated and allowed for.

It may be imagined that the distinction thus drawn of true and false between these two expressions is unnecessary, as they appear to give the same results; but the false expression leads to many deductions of very great importance and to much misconception, because it is linked with the idea of electricity existing free. Thus one of the common expressions based on it is "The intensity of an electric charge is proportional to the square of the thickness of the stratum of electric fluid on the surface." For the same reason many electrical writers would say, in reference to the experiment just referred to, that when the surface is reduced to half, the force exhibited would be fourfold, and when one-fourth sixteenfold that shown at first. This assertion is, in fact, a natural deduction from the false law, and is based on the immediately preceding expression flowing from that law. But it implies the creation of force, for if by concentrating a given force on one-fourth the surface, or by putting four times the force on the same surface, we can raise the energy sixteen times instead of four, where does this excess of energy come from? But the indications of some instruments would actually show sixteen times the force in a certain sense, and the true law shows us how this occurs, and agrees with the natural proposition that the force on a surface must increase in a ratio of its multiples, not in the ratio of the squares of the multiples.

Part of this confusion arises from the different meaning attached by writers to words: thus intensity and tension are usually considered as synonymous, but Harris used them with different meanings, and stated that while intensity varied as the squares of the quantity—the false law, tension varied directly as the quantity—the true law; this confusion is cleared off by regarding tension as the true force, and "quantity" the mode of its action, that is to say, the number of molecular paths of polarization on which the force is concentrated at each section of its circuit, multiplied by the tension there existing on them.

It may suggest itself to some inquiring mind to ask how it is that the force of a circuit is the *product* instead of the *sum* of the two quantities or forces, as the latter would be the case in mechanical strains on a rope. The explanation is that the tension of an electric circuit, though manifested at bounding surfaces, is not confined to them, but is active through the whole circuit, and thus the formula of the sum of the two quantities manifested at the two surfaces of equal and opposite tension expresses the whole force charged upon that part of the circuit which is there measured.

This discussion was requisite to elucidate the principle, but that understood, it is indifferent which formula is actually used, so long as the forces exhibited at the two sections of the circuit are equal and opposite.

72. It may be well to describe a few of the most useful forms of measures or electrometers before leaving this subject. A needle of shellac, carrying a disc or ball, may be mounted so as to turn on a needle point, like a compass, or suspended by a hair or fibre from a frame. The quadrant electrometer is a metal rod which may be fixed on the prime conductor, or any instrument, or on an insulating stand. It is fitted with an ivory or wood plate marked with degrees, from the centre of which hangs a pith ball. Harris's circular electrometer is still better though not so simple. A stem of wire curved forward at the top carries a ring, to the sides of which are fixed wires terminating in gilt balls; similar pith balls are mounted on a fine wire or straw turning on points within the ring, and moving under very slight force. Sometimes a universal joint is made in the stem, so that the instrument may be inclined, and so diminish the resistance of gravity.

In these instruments the force of repulsion is evidently balanced, setting aside friction, by the gravity overcome, that is, the weight raised a certain height; and this will be found to be proportionate, not to the angle of repulsion, but to its tangent; or where two bodies, both movable, repel each other, as with two pith balls or gold leaves, the force is proportional to the chord of the angle they form. However, very little direct information can be obtained from them. It is of course true that the two forces balance each other, and therefore the weight raised or resistance overcome is equal to the electric force employed in overcoming it. But that force is taken from the total force of the electric circuit; the circuit is also diminished in length by exactly the space the repelled bodies move through, and hence the mechanical work done by this repulsion is the measure of the inductive resistance of the space they are moved through, and whose resistance is thus removed from the circuit.

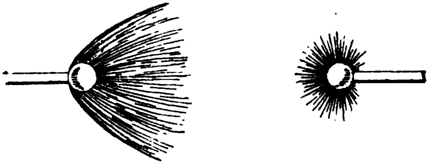
These rough instruments are only available for electricity of high tension: for more delicate purposes Harris's balance electrometer § 69 is employed, or Peltier's, which is described in most electrical text books: for purposes of extreme refinement Sir W. Thomson's quadrant electrometer is employed.

73. **Discharge.**—The effects of electrical discharge indicate that there is a real or essential difference between what are called the two electricities, that is, the actions produced at the opposite polarities of a source. Thus, if a discharge be passed through a card (which is easily done by pasting on its two sides pointed pieces of foil presented towards each other, but with their points not exactly

opposed), on insulating the card and connecting one piece of foil with the inner coating and the other with the outer coating of a jar, a spark will pass and produce a hole; this will show a burr on *both* sides, indicating that the disruptive force is not a penetrating, but a pulling one, and in so far showing a similar action on both sides, but the hole will be much nearer the − or negative pole.

But the principal evidence of this difference is found in the appearance of the discharge itself; thus the positive pole tends to produce a brush discharge, apparently spreading, while the negative tends to a bright concentrated star form. The effect is shown in Fig. 29. The appearance is modified by circumstances, such as size of the terminals, and their form as balls or points, but still the *direction* of the passage produces different effects. A brush will be produced at the extremity of a wire if rounded off, in both cases, but the negative brush is much less defined than the positive. So with the star, if a pointed wire be approached to a large ball, a star forms on the point in both cases, because it concentrates the molecular action; but if the ball be +, the star continues till the point is close to it, only becoming brighter; but if the ball be −, as the point approaches the star turns to a brush.

Fig. 29.



The nature of the medium in which the discharge occurs also greatly affects its appearance and conditions; thus, if the density of the air be increased, the resistance to discharge increases in the same ratio, and as this means a proportionate increase in the number of molecules, the reason obviously is that the tension is lowered, exactly as it would be by increase of surface in the cases previously examined, thus giving direct proof of the transmission of electricity by the tension produced on material molecules.

The nature of the medium in which the discharge occurs also greatly affects its appearance, as is seen when the discharge is effected through vacuum tubes: this is usually observed by means of induction coils, as it is by them that the effects are best manifested, but a good friction machine will well illuminate vacuum tubes and perform many of the experiments usually made with the coils.

74. One feature of electric discharge is, however, important to notice, because it is intimately connected with the theory of electricity; it is always attended with either mechanical motion or molecular disturbance. Thus, as a general rule, when the discharge is occurring there is a stream of air from the discharging points. This is shown in many electrical toys, such as the whirl, in which wires with the points bent at right angles are placed on a metal point connected to a source, and revolve as long as action continues, and in the dark, streams of light are seen issuing from the points.

But in other cases the molecular cohesion of the substances traversed by the charge is destroyed, as in the pierced card and the broken glass of an over-charged Leyden jar. These effects are similar to those of lightning; thus, if a piece of wood have two wires inserted in it so that the points approach, but are separated by a stratum of wood, a strong charge passed will shatter the wood to pieces.

Further study of the electric spark will also show us that a molecular decomposition of the discharging surface occurs, and an actual combination of its materials is produced like the actions displayed in electrolysis. If two pieces of gold leaf or tinfoil be placed on paper with the ends slightly separated, and firmly pressed between two non-conducting surfaces so as to limit the direction of discharge, it will be found that the metal is detached and spread in minute particles over the interval. So in the electric light a constant stream of molecules of carbon is detached from one pole and carried to the other, the interval being filled with carbon in the state of vapour or gas or absolute molecular division, which is, by the by, the only case in which pure carbon gas is known to be produced.

Again, the colour of the spark is modified by the nature of the surface giving it, each metal imparting its own colour, and if the medium be one capable of combining with the metal such combination occurs; in other words, which disguise the cause while stating the fact, the metal is burnt; really, a combination takes place analogous to that which occurs at the anode in cases of galvanic action, for it is obviously not caused by heat, as in no case is the metal raised to the required temperature, see § 193. Those who wish to examine more completely the nature of the inductive circuit of static electricity will find the subject very fully worked out in Mr. Webb's 'Accumulation and Conduction of Electricity.'

CHAPTER III.

MAGNETISM.

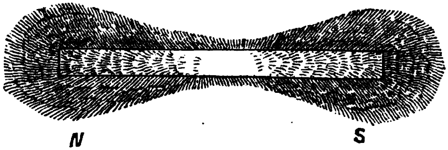
75. The purpose of this chapter is not to treat of magnetism and its phenomena on their own account, but only to deal with them so far as they are connected with or throw a light upon Electricity.

The magnetic property of a natural substance, Ferrosoferric Oxide F_3O_4 or $FeO + Fe_2O_3$, known as the loadstone, was discovered in early times from its power of attracting and adhering to iron. It was afterwards discovered that the loadstone imparted its powers to steel, and that masses of steel thus acquired a variety of peculiar properties besides that of merely attracting iron.

The first striking property is a directive power by which a bar of magnetized steel always places itself in one position, with one end pointing towards the north; the next is that when two such bars approach each other, two of the ends attract and two repel each other, instead of displaying a constant attraction, as with iron.

76. In examining these properties we find that the force, be it what it may, which is acting, is concentrated mainly at the two ends of the bar, towards which the holding power on iron is greatest; thus, if a bar magnet be rolled in a mass of iron filings, these will adhere to it in the manner shown in Fig. 30; so if it is measured by the actions on a suspended needle, the force is represented mathematically by a curve shown in Fig. 31, which exhibits half a bar magnet, and shows that the point of greatest force, or what is called the pole, is not at the actual extremity, but a distance within, varying with the length and form of the magnet.

FIG. 30.



These figures are identical with those which represent the distribution of electricity according to the laws discussed in § 70, and hence there was early perceived a relation between magnetism and electricity, and this naturally, in times when men never hesitated to create any power which would serve to explain a fact, led to the hypothesis of two magnetic fluids, the Austral and Boreal, now entirely abandoned, although their brethren, the electric fluids, are still cherished by many philosophers.

FIG. 31.

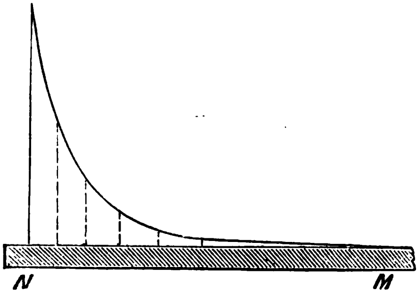
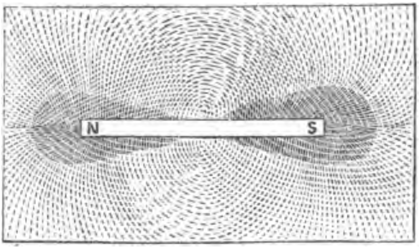


FIG. 32.

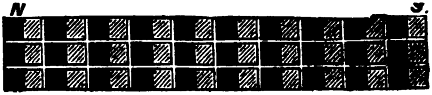


77. A remarkable feature in magnetic force is that it apparently acts at a distance without relation to intervening substances, providing these are not themselves magnetic. Hence a magnet acts just as powerfully through a sheet of glass as through air. If therefore we place a sheet of glass over a bar magnet, and sift iron filings over it, these arrange themselves in obedience to the force, if we lightly tap the glass to aid them in moving. Fig. 32 shows the result, the filings arranging themselves in closed curves, which exhibit the lines of force surrounding the magnet, and on which, or, rather, on the tangent to which, at any part, a suspended magnetic needle will place itself. This figure represents therefore a section

of a magnetic field; the field itself of course extending round the magnet in all directions. It also enables us to perceive that magnets do not act simply at a distance; they induce in all surrounding matter a condition which is the source of magnetic action; but it is only some forms of matter, of which iron is the most important, which render this condition active as magnetic force, and are themselves capable of retaining that condition, and transmitting it afresh.

78. To ascertain what this condition is, we must examine the magnet itself. Thus far we see in it a repetition merely of the electrified cylinders in Fig. 25 with the + and – charges apparently collected upon their separate ends. If, however, one of those cylinders was capable of division across the middle, we might obtain the two parts in the opposite states, one wholly + the other wholly –, and there is thus some ground for the idea that we have really separated two fluids; but this is not the case if we break a magnet across, for we find that two perfect magnets are produced, two fresh and opposite poles being generated out of the previously inert middle, while the forces these possess are taken from the original terminal poles, the attractive powers of which are reduced. We may repeat this process to an unlimited extent, till we convince ourselves that the perfect magnetic power resides in every minute particle; in fact, that magnetism is a force belonging to and residing in the molecules of which the magnet is composed. This view of the nature of a magnet is well expressed by Fig. 33.

FIG. 33.

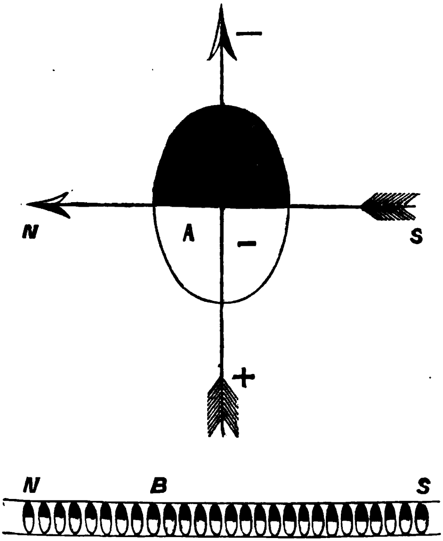


This presents the magnet as consisting of a collection of polarized molecules symmetrically arranged, the force of each series exhibited at its two ends, and completing its circuit of polarization or force through surrounding matter in the curves shown in Fig. 32. This conception is strictly correct as to the facts of magnetism itself; but when we come to the theory and to the evident connection of magnetism and electricity, it is apt to generate confusion of ideas, owing to the apparent resemblance between the polarized molecules in both cases.

79. To avoid this confusion, and more intelligently to examine the facts and the true relation of the two forces to each other, and to the molecules of matter, it is desirable to define those relations in accordance with the views arrived at as to the relations of elec-

tricity to matter. Electricity and magnetism then are the same force, and are two actions of polarized molecules, manifested at right angles to each other, and both developed together. Electricity is the action which occurs *in the line of polarization.* Magnetism is the action which occurs *at right angles to the line of polarization*, and in all directions at right angles to that line. But there are some important distinctions to be noticed. Electricity is essentially a dynamic force; its nature consists in producing motion in, and transmitting energy along, the polarized chains; its static actions are only incidents of this process, dependent on the resistance offered to the completed motion. Magnetism is, on the other hand, purely static; it consists in the storing up of energy in the polarized molecules. It should also be remarked that while magnetism is an essential consequence of and attendant upon electric polarization, it is only manifested as magnetic action by certain substances which possess the faculty of assuming that condition which constitutes a magnet; of these iron, nickel, and cobalt, are the most effective, and this state is more readily produced and manifested by dynamic electricity of large quantity than by static electricity of high tension. Considered from this point of view, Fig. 34 A represents a typical molecule, and this figure once

Fig. 34.



thoroughly mastered and fixed in the memory will answer every possible question as to the relations of magnets and currents, the action of helices, galvanometers, coils, &c. A magnet will always place itself at right angles to such a molecule (forming of course part of a polarized chain), with its north end to the left hand, looking from the molecule itself, so that the arrow or magnet N S is supposed to be on the farther side of the molecule. There is, however, no true directive force in this action, no north and south *sides* to the molecule itself, as there are + and – *ends*, but the directive tendency is the same at right angles to *any radius* of the molecule at right angles to its line of polarization. Thus, if the molecule be vertical, and a suspended needle be carried round it, the needle will retain the same relative direction to the molecule, but will make an entire revolution on its own axis, and its extremities will point in turn to every direction, provided the directive action of the earth is neutralized, as by a fixed reversed magnet. The reason of this is shown in Fig. 34 B. The polarized molecules of the magnet are ranged, not in the line of magnetic force, as in Fig. 33, but at right angles to this line and round the sections of the magnet.

This is a necessary consequence of the definition, because it is only thus that the lines of polarization can be at right angles to the line of magnetic energy. Hence the directive energy of the magnet is due to the inductive action of the energized molecules, tending to range all neighbouring molecules in the same order as themselves. They thus set up a magnetic field (which is a resolution of the forces exerted by the various acting molecules) in which all the particles of air and common matter range themselves, like the filings in Fig. 32: when a magnetic body enters this field its molecules range themselves in obedience to it, and by their own power set up a field of their own; when the body entering the field is already magnetized permanently, and therefore has its molecules already so ranged, or is temporarily magnetized circularly by being the conductor of an electric current, then if movable as a mass, it is turned or attracted or apparently repelled in such manner as to most energetically form part of the original lines of force or magnetic field; but if it cannot move it reacts upon the field and moves the magnet if movable, and a new field is set up which is the resolution of the forces of the two or more magnets within it.

B Fig. 34 is a filament or row of molecules, forming part of a magnet which is built up of many such rows, forming circles of polarized molecules, which retain that polarization because they are so completed or closed.

80. If a magnet (which for this purpose B Fig. 34 will represent)

be placed *below* the electric molecule or current, this filament is the upper line or side of the magnet, and will range itself as drawn, and on the arrow N S; but if the magnet be *above* the molecule the filament is the lowermost one, and the position would be reversed, in order to bring N to the left of the molecule looking upwards; the vertical arrow + – represents the line of polarization, or current of which the molecule forms part, + being the positive pole at any intersection of it.

This figure represents in fact Ampère's illustration of the relation of magnets and currents; for let the reader conceive himself *to be the molecule*, the current of which he forms part entering at his feet, his head therefore being the + extremity; his right hand will have the magnetic actions of a N pole to any object at which he is looking, and therefore any magnet in front of him will present its N end to his left-hand, the magnet itself standing fairly across him in front in whatever direction he may turn.

81. DIAMAGNETISM.—By means of electrical currents, which consist of energetic polarization of the molecules of the bodies they traverse, and which induce similar and parallel lines of polarization in all surrounding bodies, magnetic effects can be developed in all substances, and Faraday and others, by means of very powerful magnets, have proved that magnetic actions do thus occur, modified by the nature of the substances and their molecular arrangement, which lead to a classification of substances, as magnetic and diamagnetic.

The first class, when interposed between the poles of a magnet, place themselves with their longer axis in the line joining the poles; the latter arrange themselves across that line. There has been a tendency among some philosophers to attribute this to a force distinct from magnetism, but there seems no sufficient reason for it, as the properties of the magnetic field will explain the facts; it would seem more probable that the diamagnetic substances are those in which the faculty of assuming the magnetic condition is feebler than in air, and that therefore the molecules of air form the field more readily than those of, say, bismuth, and consequently move these latter into the position in which they take up the least portion of the lines of force; thus a tube containing a weak iron solution will be magnetic in air, but suspended in a vessel containing a stronger solution of iron it acts as a diamagnetic substance. Diamagnetism will not be further entered upon in this work.

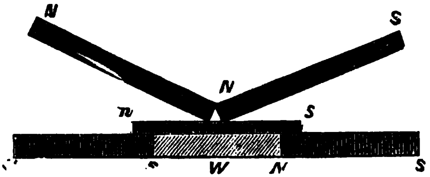
82. Whenever iron is attracted, magnetic polarity is induced in it, and the attraction results from that process. That is to say, the attraction is for the magnetism, not for the mere iron; but on removal from the inducing magnet, the iron returns almost entirely to its previous inert or unpolarized state. Steel, on the other hand,

is much less strongly attracted, but retains the polar state; both circumstances resulting from a resistance in the molecules to an alteration in their state. This, no doubt, is connected with the fact that steel is a compound of carbon and iron, and thus its molecules are very different from those composed of two atoms of iron only. This resistance is termed the *coercive force* of steel, which varies very much in different samples. Those in which the coercive force is greatest are the hardest to magnetize, but make the strongest and most perfect magnets. This property, therefore, furnishes a limit to the magnetism any steel can possess, and is called its point of saturation; temporary power may be given beyond this, but will speedily be lost. Another element in the power of a magnet is the force of the source from which it was derived; thus, if magnetized from another magnet, its force cannot exceed that of the magnet used: that is to say, its specific magnetic intensity, or relative molecular force in proportion to weight; hence powerful magnets should be employed to impart the force.

83. **MAGNETIZATION.**—Steel may have magnetic power developed in it by drawing a bar magnet along its several surfaces, always in one direction, or the same process may be adopted with a horseshoe magnet; in both cases it is still better to arrange a complete system of bars forming an octagon or square, and draw the magnet round and round, always in one direction; in this plan the bars may be all steel, or alternate steel and iron.

If the operator has two bar magnets, an excellent plan is to place them with opposite poles together over the middle of the bar to be magnetized, and then to draw them slowly asunder to the ends, repeating this six or eight times on each face. This process is still more effective if the ends of the bar rest on two other magnetic bars with their opposed poles in the same direction as the moving magnets. Fig. 35 shows this process, *n s* being the bar to be magnetized and W a piece of wood to support it and steady the lower magnets. This is called the method of single touch, and is best suited to thin needles and bars, not more than a quarter inch in thickness.

FIG. 35.



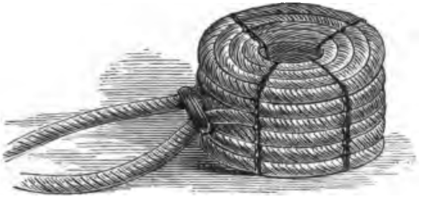
The method of double touch may be illustrated by the same figure.

The triangular space between the two movable magnets is filled with a piece of wood, and their upper ends connected by a bar of soft iron, and both are moved to and fro along the bar *n s*, without separation. This process gives more magnetic power than the other, but it is apt to be irregular, and to produce *consequent points*, that is to say, reversals of magnetic polarity within the bar, which then acts as if it were composed of several shorter bars, with similar poles in contact.

In magnetizing steel in the horseshoe form, two should be placed with their ends together, and the magnets carried round the system, or if two are not needed the ends should be closed with an iron armature.

84. **The Battery Process.**—This is the most effective, and will develop the greatest power; needles may be magnetized by enclosing them in a helix extending their whole length and passing a strong current for a few minutes, for which see § 171. For large bars and horseshoes the instrument Fig. 36 is well suited. It is a short helix of stout covered wire, the central opening of which is large enough to allow it to be passed over the bar. It should be arranged at the middle of the bar, and connected to a battery sending a powerful current through it, and regularly passed along the length both ways several times, allowing the ends to half enter the helix, and brought back to the middle before the current is stopped; the action is facilitated by slightly tapping the magnet during the process to produce vibration. An ordinary electro-magnet may also be used for the touch processes, in the same way as a permanent steel magnet, and has the advantage of great intensity of magnetism.

Fig. 36.



85. **Quality of Steel, and Temper.**—For large magnets, hardened cast steel is best; for compound horseshoe magnets the same steel annealed at 500°, or hard shear steel; for needles, cast steel annealed in boiling oil. Steel made of the best iron,

such as Swedish, makes the best magnets, and the hardening or tempering should be equal throughout.

86. FORM AND ARRANGEMENT.—For compass needles, the best form is flat, tapering from the middle to the points; for bar and horseshoe magnets, the mass of material should be divided into a number of plates not exceeding a quarter inch in thickness, separately tempered and magnetized, and arranged with their similar poles together; they should be insulated from each other by sheet brass, or cardboard, and bound together either by screws or external bands of brass. The ends should not be flat, but tapering, so as to concentrate the action on small terminal surfaces; and in some cases it is well to terminate the whole by pieces of very pure soft iron, shaped as desired, fitted to the end of the bars, and secured to them.

Very powerful magnets have been made of late from very thin steel plates, similar to that used for clock springs, the ends gathered into terminal blocks as just mentioned.

87. When a number of bars are thus united, the total force is never equal to the sum of the whole separately, because the similar poles tend to neutralize each other; in some cases the central bars will even be reversed by this action, for which reason they should be the longest. This is the reason, together with the superior temper of the surfaces, that a number of separate pieces give more power than a solid bar of the same mass, as in this the interior portions are apt to take reverse magnetism to the exterior, thus completing closed magnetic circuits, and leaving little force to be exerted on external objects.

88. PRESERVATION OF MAGNETS. — They should be carefully handled, and all jarring actions avoided; when not in use needles should be placed in the true magnetic direction; the same with bars; but either may be still better preserved by placing two together with their poles reversed, and a small piece of soft iron between them at each end. Horseshoes should always have the keeper or armature on, and their powers may be greatly increased by hanging them up with a weight attached, which can be gradually increased. Care should be taken, however, never to violently detach the keeper, and when this is removed for use, it should be done by sliding it off across the poles, not by pulling it away.

89. THE DIRECTIVE FORCE.—A magnet capable of free motion, if approached by another magnet, is attracted by this, if extremities of opposite names are nearest, and the ends of similar names repel each other. This repulsion, however, like that of electricity, is only apparent; it is the consequence of the fundamental principle of magnetism, the polarity of the molecules. It is simply the effort of these molecules to place themselves in the parallel and

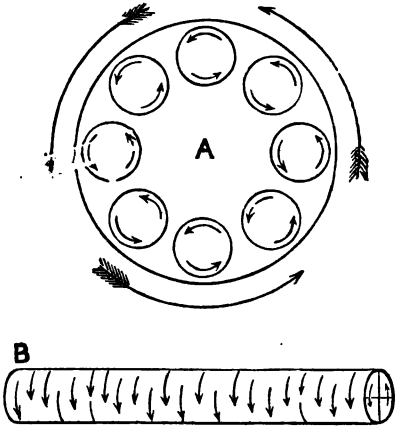
consecutive order described in § 80. In soft iron this is effected by molecular reversal; the coercive force of steel resists this, and therefore the mass of the magnet tends to turn round to effect the same result, and if this be resisted the molecular action very commonly occurs, resulting in the permanent weakening of the magnetism, or even in the total reversal of that of the magnet whose intensity is least. The direction in which the free needle will arrange itself depends on the positions and distances; in fact, it ranges itself on the lines of the magnetic force of the fixed magnet, viz. on the curves shown in Fig. 32, and the apparent repulsion as well as attraction are due, not simply to the visible bodies or magnets, but to these lines of force or chains of polarized particles of air, &c., which surround them to a considerable distance. This is very distinctly shown by the process of attraction upon iron. If a piece of soft iron is applied to the N. end of a bar magnet, it is attracted because polarity is induced in it; it becomes itself a magnet with its S. end in contact with the magnet. If, now, a second bar magnet is applied with its S. end to the other end of the iron, the action is increased, the iron held with double force; but if the N. end of this second bar be applied, the two actions neutralize each other, and the iron, though in contact with two magnets, will have only a slight attraction exerted upon it.

90. The earth itself acts as a large magnet, and hence a free magnet arranges itself in relation to the magnetic poles of the earth, which are not at the same points as the true poles of its axis of revolution, nor are they even permanently fixed. The consequence is that the compass does not point true North and South, nor exactly in the same direction at all times. So also it does not rest in a horizontal direction, but in the northern hemisphere, with its N. pole lowest, or *dipping*, pointing to the magnetic pole, and thus occupying the magnetic curves of the earth in a manner exactly similar to the behaviour of a suspended magnetic needle in relation to a large bar magnet. Terrestrial magnetism is a subject by itself, and one of vast practical interest, but it is out of the scope of the present work. Our concern with it is simply to regard the earth as a huge magnet, and to understand that its actions are the same as those of any other magnet.

91. AMPÈRE'S THEORY.—As before remarked, magnetism was formerly explained by the invention of two fluids; but the theory now universally received is that of Ampère. Working from the fact that a circular electrical current constitutes a magnet at right angles to its plane, and that electro-magnets are practically composed of a series of such circular currents ranged in the form of helices, and also from the fact that the force is evidently possessed completely by the molecules of permanent magnets, he taught that

magnetic substances are composed of molecules around which currents of electricity are constantly flowing; that magnetism consists in ranging all these currents in parallel order, and it has been thoroughly proved by the most stringent mathematical analysis, that this beautiful idea explains all the facts of magnetism. Fig. 37 exhibits this theory. A is a cross section, showing the supposed molecular currents, the sum of which acts like an external current, and B represents a cylindrical magnet, of which A is the end shown, or any section looked at from that end.

FIG. 37.

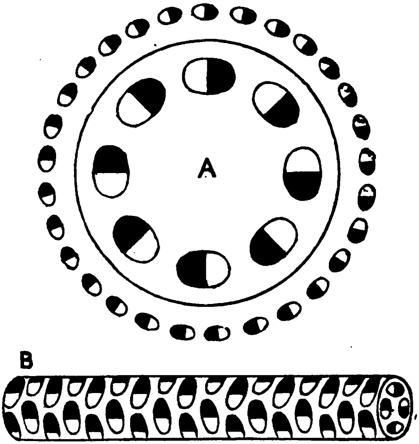


92. Beautifully scientific as this theory is, there are fatal objections to it, not generally seen. In the first place, it is based on the idea of electricity being an entity, a something which can circulate round the molecules in a real stream, and therefore it is inconsistent with more recent views as to the nature of electricity; but apart from this, though we might assume it to be possible that such circulating currents might be confined to the molecules, it is impossible to conceive how they fail to arrange themselves symmetrically always, or why, once arranged, as in magnetized iron, they derange themselves at once the moment the inducing magnet is withdrawn. The very nature of electric currents would require a *coercive force* to prevent the magnetic condition being always existent, whereas the reverse is the fact.

93. THE MOLECULAR THEORY.—The theory of electricity set forth in the foregoing pages and extended to magnetism, § 80,

takes possession of all Ampère's work, and adopts all the facts and all the mathematical problems and proofs based upon them: all of these are unaffected by the substitution for the assumed circulating molecular currents, of the conception of the polarized molecule exerting influence upon all the neighbouring molecules and arranging them in systematic polar order. Fig. 38 shows at a glance both the resemblances and differences of the two theories.

Fig. 38.



A, regarded as a permanent magnet, shows the molecules retained as a polarized chain, analogous to the conditions of static electricity, and it shows how an electric current generates this state in a bar around which it circulates. The coercive force of the magnet is due to the resistance of the molecules to the change of condition, either to being magnetized or demagnetized in the case of steel, the molecules of which are compound, while iron has little power to resist either. What it is in the molecules of iron and steel which gives them these properties, we do not know.

94. Laws of Magnetic Force.—Many attempts have been made to fix the laws of attractive force of magnets, and the result appears to be that it varies inversely as the square of the distance, as it must indeed from the cause which generates this universal law of actions proceeding from a centre, this being a necessary consequence of the fact that the areas of spheres increase in that ratio; but this only applies to each point of a magnet regarded by itself; practically no distinct law can be laid down, as the force is a com-

pound action and varies with the form of the magnet. Thus the poles of a magnet are the centres of action of each half of the magnet, not necessarily the points where attraction is strongest, which is usually at the end, while the poles are generally at about two-thirds the distance from the centre to the ends, and in tapering needles, still nearer to the centre. As to the attractive force or weight-supporting power, this varies with the quality of the steel and also with its form, length being the chief element in this latter. For the relative powers of magnets see § 95.

The vibrations of a magnet obey the same laws as those of pendulums, that is to say, they take the same time for each oscillation, whether large or small.

95. **Magnetic Moment.**—This mathematical term frequently causes much difficulty to those unacquainted with the higher mathematics and mechanics. Its full explanation does not come within the scope of this work; all that can be attempted is such an explanation as is possible without elaborate formulæ.

In mechanics the "moment" of a force is its value under given circumstances, as of the force applied to a lever to move it around its fulcrum. A magnet is a lever, its centre the fulcrum, its poles the points at which the force is applied, and therefore the length of leverage. "Moment," therefore, is compound, and the moment of a magnet depends upon the specific intensity of its magnetism, and upon its length; this gives the common expression $m\,l$. The poles of a magnet have no real existence, their position varies with surrounding conditions, they are really only a term to express the theoretical point which acts as the focus of the energy exerted under any given conditions by each half of the magnet; the poles, therefore, are never the extreme ends of the magnet, but at a point within the ends varying with the shape of the magnet.

The moments of magnets may be compared by their relative actions as regards another magnet; if we use the earth as this magnet (and do not need the high accuracy which would take into account the varying magnetic intensity of the earth itself) the moment of a bar magnet may be measured by suspending it by a fibre and counting the time of one oscillation, or the number of oscillations in a given time, the relative moments are the square of the number of oscillations, or inversely as the square of the time of one oscillation.

The moment of the magnet may be ascertained in absolute measurement upon the same principles as those of the tangent galvanometer, § 176.

A very short needle is freely suspended so as to hang in the magnetic meridian over a zero line. The magnet to be measured is placed upon this line, at right angles to it and in the plane of the needle, at such a distance that it produces a deflection of only a few degrees. Let θ be the angle of deflection, d the distance in metres between the centres of the needles, H the horizontal component of the earth's magnetism (say 1·764), then $ml = \mathrm{H}\,d^3 \tan.\ \theta$.

Horseshoe magnets may be similarly measured if their ends are placed on the line which a bar would occupy, and the distance measured from the central points between them.

The "intensity" of a magnet may be considered as the relation of the force to the mass of matter it is charged on, and therefore varies as the ratio of the magnetic moment to the weight or volume of the magnet; thus, if one bar has a magnetic moment equal to that of another of the same length but double its weight, it is itself magnetized to twice the intensity.

These considerations are of importance in the construction of galvanometers, as will be seen § 173.

Before leaving the subject of magnetism, it will be well to point out the error of the common conception of magnets as inexhaustible sources of force. It is this misconception which has led so many to waste their time in trying to devise perpetual-motion machines, of which magnetism was to supply the motive power.

Magnets, like springs, can only exert the power which has been put into them; *they have no force of their own.* In the act of magnetizing, whether by magnets or by electricity, a certain amount of energy is charged upon the molecules, just as it would if each of the molecules in Fig. 33, p. 65, were a spring which was wound up in the act of magnetizing. When the magnet exerts any force, *it parts with that force;* it is to that extent exhausted, and the energy it parts with is distributed over the new "field," or in the armature, &c., which has been moved. If the armature is a mass of iron as large and heavy as the magnet can hold, the magnet is exhausted; it will no longer affect external magnets, &c., or but very slightly. Before the magnet can exert any further force, the requisite energy must be restored to its molecules. This is done by removing the armature, which requires an exertion of force equal to that the magnet exerted in attracting it.

The distinction is simple, but important; the common idea regards the removal of the armature as an exertion of force against the power of the magnet, and in some sense this is so. But the real action is the restoring to the molecules of the magnet the force which it has given up to its outer circuit, which is effected by the molecules themselves so long as they retain the magnetic condition.

CHAPTER IV.

GALVANIC BATTERIES.

96. It is difficult to examine the facts of galvanism thoroughly in any progressive order. It appears best to commence with examining practically the various sources of the force, the different forms of battery; but this can be done only by the aid of knowledge of a much higher order. Students, therefore, must needs go over this ground twice, assuming at first the principles and laws necessary to understand the facts, and returning to these again after the study of those principles of measurement, &c., based upon the facts.

97. If we place a piece of ordinary sheet zinc in a dilute acid, we find that a tumultuous action takes place, the zinc is dissolved, and hydrogen gas is given off. Another effect is produced which is seldom set forth when this fundamental experiment is stated; as the zinc dissolves, the liquid becomes heated. Now this last fact is the one of primary importance; for with all the similar facts in chemistry, it teaches us that whenever an action takes place spontaneously between two substances, heat or energy is set free. Let us examine, though only cursorily, what occurs in this instance, and why it occurs. The full explanation will be found in Chapter VIII.

The old explanation, and one even now frequently given, is that the zinc decomposes water, H_2O, gives off the hydrogen and forms oxide of zinc, ZnO, which is then dissolved by the acid, forming a salt of zinc. The true explanation is far more simple; the acids are substances in which hydrogen forms the base, united with a special acid radical; hydrogen, though a gas, and one which has never yet been liquefied, has many chemical analogies with the metals, and, indeed, there is good reason to believe that it is a true metal, and capable of assuming the solid metallic state in alloy with some other metals, being then a conductor of electricity, and displaying the ordinary physical characteristics of metals. At all events, metals are capable of taking its place in compounds; and thus in the case under consideration, say of zinc acting on dilute sulphuric acid, H_2SO_4, the metal merely displaces the hydrogen and converts the substance into $ZnSO_4$, sulphate of zinc, instead of sulphate of hydrogen.

98. It is requisite to clearly understand, that besides the material elements, *energy* enters into the constitution of all bodies; all possess a specific quantity of what we know as heat, and according to the molecular theories, the atoms of which all substances are composed are in a constant state of internal motion; the amount of that motion governing the physical state, as solid, liquid, or gaseous, and also the chemical relations; affinity is, in fact, a function of these motions (and very probably dependent upon the wave lengths of the vibrations proper to each element, as shown by the spectroscope); the less the motion, the nearer the atoms approach, and the greater the attraction they exert on each other. Hence, when what are called *higher affinities* come into action, the internal motions are diminished; but, as a consequence, this motion becomes external, active and sensible, instead of internal or latent; and thus it is that every act of chemical combination sets energy free in some form, usually as heat, while every act of chemical decomposition requires the supply of energy to re-establish the internal motions, or latent forces, or, as it is usually expressed, to overcome the chemical affinities. Indeed, as in many other cases, we are gradually finding a truth in an ancient delusion; for, in modern science, *energy* or internal motion is gradually assuming the position of phlogiston in the old chemistry.

99. Thus, when zinc is dissolving it gives off hydrogen and *heat* while forming the more satisfied compound, sulphate of zinc. If we use a piece of iron it does the same, but if we use copper, no such action occurs. Now, if we place in the same sulphuric acid, copper and zinc, but separate from each other, we see gas pouring off the zinc and not from the copper; but if we permit them to touch a new phenomenon occurs: the gas appears to issue abundantly from the copper. Still if we examine the liquid we find that no copper is dissolving, while the zinc is dissolving faster than before. Instead of allowing the two metals to touch within the liquid, we connect them by a wire, and we find that this wire is suddenly endowed with extraordinary properties; if it approaches a magnetic needle the earth's directive power is superseded, and the needle no longer points N. and S., but places itself across the wire, and in different directions, according as it is above or below; if the wire be coiled round a piece of iron, it endows it with powerful magnetic properties; if the wire be cut in two, and its ends dipped in liquids, it produces chemical changes in many of these; lastly, the wire itself becomes hot. But in proportion as these effects are developed, so does the dissolving zinc generate less and less heat in the liquid. Here we have the explanation of the sources of these

external actions: there is no creation of energy; nothing new occurs, except that, under the new conditions, the energy set free by the combination of the zinc takes that form which we call electricity, instead of the other form we call heat (just as it was seen occurs with friction, § 15), and is capable of manifesting itself by its magnetic, chemical, or calorific effects, thus furnishing the three natural divisions of the study of dynamic electricity.

100. The conditions under which the energy takes this form are a development of those pointed out in § 29, but more plainly evidenced. The fundamental condition is a complete circuit of molecules, and the whole of conducting substances; where the electricity is developed by chemical action, part of the circuit must be a liquid, an electrolyte; that is, a substance whose molecules will readily assume the condition of polarity, and break up into two distinct parts, and one which will give up energy in the act.

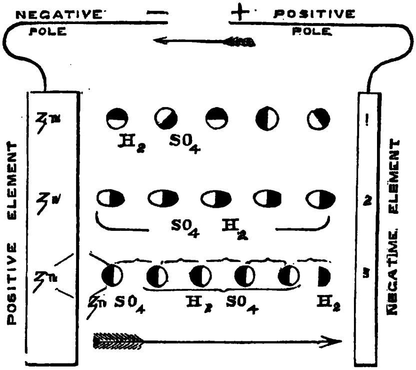
This action occurs under the influence of the zinc, which, as it attracts the sulphuric radical, turns the hydrogen half of the molecule away from itself, and by diminishing the internal attractions of this first molecule, disturbs those of others, if there be this complete chain provided along which the force can act; if not, the hydrogen simply escapes, and the heat is at once set free. The action can be traced by the ordinary chemical symbols. $Zn + H_2SO_4$ must evidently first become $Zn + SO_4H_2$, then $ZnSO_4 + H_2$. The atoms of hydrogen are now what is called *nascent*, but they instantly form a free molecule, taking up and rendering latent that portion of heat or energy necessary to convert them into a gas; but before this process is completed they are in a condition of great activity, and eager for combination, but as they are surrounded only by molecules the nature of which they would not change, i.e. hydrogen compounds, they are compelled to become free, but where this complete circuit of molecules capable of polarization and discharge is provided, this action is deferred; molecule after molecule is decomposed, and the hydrogen is not set free until it reaches a point at which its *nascent* energy is powerless to effect a decomposition, and thus in the combination under examination it reaches the copper plate before it becomes free; it does not do so at all if it can help it, for if a reducible metallic salt is present at the copper plate, such as sulphate of copper, it displaces the copper, which fixes itself in turn upon the superficial molecules of the metallic plate, to which the polarizing force is transferred; in fact, that action occurs which in the conditions absorbs the least amount of energy.

101. These two processes furnish us with a natural division of generators or batteries into two classes: (1) Those in which the hydrogen gas is set free; (2) Those in which the hydrogen is not set free, but displaces some other substance; and this latter

class consists of two kinds, those in which one liquid fulfils all the requirements, and those in which two separate liquids are required, kept apart by a porous diaphragm or partition.

Before examining these various forms, it will be as well to explain various terms as to which there is much confusion in many minds. As the action commences at the surface of contact of the zinc with the acid, the zinc is called the positive *metal* or element: and hence the order of polarization originated there in the liquid is such that the positive or + ends of the molecules are turned from the zinc, and consequently all the negative ends, which are the acid radicals, are turned towards it. This also corresponds with the terms of static electricity, and shows the wire united to the zinc plate and called its pole, in the same electrical condition as the rubber of a glass electrical machine — or negative. The action passing through the liquid to the copper or other collecting plate polarizes its molecules with their — ends to the liquid, and their + or positive ends towards its wire. Hence we have the zinc, the positive *metal*, *plate*, or *element*, but its wire, the negative or — pole; the copper is the negative *plate* or *metal*, but the wire proceeding from it the positive or + *pole;* Fig. 39 shows this, together with one series of the reactions shown in their successive stages. Line 1 exhibits the arrangement before action, the molecules indifferent, the shaded part representing the + or metallic or basic element or half; the white being the — or acid half. In line 2 we see the molecules polarized under the attraction of the zinc; in line 3 the resulting discharge, the whole chain simultaneously breaking up

Fig. 39.



one atom of zinc forming a molecule of zinc sulphate; and at the other end of the chain, the two atoms of hydrogen, which are equivalent to one of zinc, are set free, when they satisfy each other's attractions, and together form a gaseous molecule of hydrogen. This step being reached, polarization again takes place, the molecules making a semi-revolution, and resuming the position of line 2. It will be seen that this view of the action involves two exertions of force at each stage, first the mechanical semi-revolution of the molecules on their axes; and, secondly, the overcoming the chemical attraction within the molecules; this latter also involves two separate actions, the actual disruption, which occurs only as to one molecule of the chain, and the temporary disruption and re-forming of all the other molecules in each chain. This is indicated here because it presents itself, and because the more clearly these various principles are seen, the more thoroughly the subject will be mastered. These various actions cause the internal resistance of batteries, while the energy given up during the interchange of zinc for hydrogen in sulphuric acid is the source of the electromotive force.

102. That this condition of polarization or strain tending to disruption really does occur in this case is manifest, because although actual disruption can only happen when the whole chain is composed of conducting materials, yet the tension which tends to produce it exists exactly as in the cases studied under static electricity. If the two wires are connected to a delicate electroscope, the two plates will be found to exhibit electric tension exactly as if they were connected to a machine. This indicates the existence of the complete chain, the air or dielectric between the plates of the condenser being polarized; connect the plates by a conductor, and discharge and current are produced.

103. In all forms of galvanic generators there are a set of general principles involved which, once understood, explain the uses and values of each form.

Electrical operations, like mechanical ones, consist of two distinct parts. (1) The generation or collection of energy from some source. (2) The application of that energy to effect the desired purpose, and this latter is divisible into two parts, that is to say, the conveying the energy to its work, in which process it is partially expended, and doing the actual work. Be the work we have to do what it may, one universal law governs all; we must expend in doing it energy equivalent to the work and all the operations incidental to it; under no circumstances will the work do, or help to do, itself; this may seem a mere truism, yet the want of understanding it costs this country many thousands every year. Economy, that is true practical working, consists in obtaining the necessary energy at the lowest cost, and in avoiding all loss in applying it when obtained.

Thus, in ordinary mechanics, it is necessary to select the cheapest fuel, the best furnaces and boilers, then to avoid loss of heat in the steam pipes, or undue friction in the engine and connected machinery: at every stage there is room for a wise understanding of principles, and a due application of them. Electrical operations are perfectly analogous and require similar attention. The battery or other motor represents the boiler with its fuel, the conducting wires replace the steam pipes, and the work to be done and apparatus for doing it are the analogue of the engine and the machinery it may drive; while the steam itself, with its capacity for bearing pressure, and thus conveying the energy derived from the combustion of the fuel, strongly resembles the electric "current," with the various tensions which set it up and give it power.

We are thus led to the three fundamental expressions employed in the laws of electricity known as Ohm's formulæ, viz. electromotive force, resistance, and current. It is upon a clear understanding of these, in a perfectly definite form in place of the confusion of the old vague terms "quantity and intensity," that sound and economical working must be based.

104. The explanation of these terms will be found §§ 198–204; at present we have only to resume the consideration of the general relations of matter and force at the point to which § 13 had reached. The various relations then described are perfectly definite, and the greatest advance of modern science has been the doctrine of Correlation of Force, the understanding, that is, that these forces have definite values and are capable of mutual exchanges of equal values, just as we exchange notes for gold, silver, or copper coins of equal value.

105. The form of energy which gives most definite ideas to the general mind is mechanical exertion, the lifting of a weight.

The usual unit for measurement for mechanical energy in this country is the foot-pound, that is to say, the work expended in lifting a pound weight one foot against the force of gravity; and as all the different forms of work or energy are interchangeable in definite or equivalent values, from this unit we can ascertain the corresponding value as heat or as electrical action, in a form more definite to most minds than the special units. Every conceivable action, therefore, may be expressed in foot-pounds; so also every effort made, every action performed against any resistance, requires a definite expenditure of so many foot-pounds of energy, every chemical action either produces or absorbs its own definite value; and it may be stated in broad terms that every act of chemical combination gives out energy, and every act of chemical decomposition absorbs or requires energy to be put into it. Thus, when we burn any substance, we get energy given out as heat; when we want to reduce or unburn a substance, as in obtaining a metal from its ore, we must put back that heat into it, and we must put back exactly the same heat as it would give up in burning.

106. Combustion is the union with oxygen at a rapid rate, but in principle it is simply a chemical combination, and all combinations obey the same laws; each individual combination gives out a definite or specific amount of energy, and to decompose that combination, *exactly that same energy* must be put back into the elements of the substance. This is what is effected by the chemical actions of the galvanic current.

Carbon, when burnt in oxygen, gives per lb. 11,228,000 foot-lbs.; hydrogen, 47,887,000; and coal, which is a compound of these, has a similar theoretical value, of which, from the various sources of waste, only about one-tenth appears available in the steam engine, and much less, again, in actual work done.. Zinc burnt in oxygen gives per lb. about 1,845,000 foot-lbs.

107. But if any real knowledge is desired we must dismiss pounds from our consideration, because we must go to nature for our knowledge, and nature employs no pound weights in her operations, she uses only atoms, molecules, and equivalents, as defined §§ 2–12, to which definitions we must now add individual exactness, that is to say, we must consider the quantity of matter which nature puts into each of her atoms, that is, the atomic weight and the valency (§ 6) of the atoms of each element; for the relation of electricity to matter, its passage through, and its effects upon, various substances are absolutely linked to, and wholly dependent upon, the atomic weights of the various substances, upon the valency of the atoms, and upon the consequent construction of the molecules of each distinct substance. (§ 9.)

108. Gravitation acts upon matter according to its mere mass, without relation to its nature; or, more truly, weight, our measure of the quantity of matter, is due to gravitation; but heat, electricity, and all the forces which act within matter rather than externally, have a selective power: they act differently on different forms of matter, and upon examination it is found that these forces act, not upon mere masses, but upon the atoms and molecules of which the masses are built up; their actions are related to the atomic weights and the valency of the several atoms. Thus a pound weight of iron would require twice as much heat to raise it to a certain temperature as a pound of silver would, but equal quantities of heat would raise to the same temperature an atom of iron 56 and an atom of silver 108. This relation is called the specific heat of substances, § 196.

But when electricity passes through solutions of these two metals, an entirely different condition arises. It would require just twice as much current (or twice the time with equal current) to deposit 56 of iron as it would 108 of silver: the reason is that the 1 atom of iron has two valencies, or stands chemically (in ferrous salts) in place of 2 atoms of hydrogen, while 1 atom of silver is equivalent to 1 of hydrogen. Thus it appears that heat is absorbed by matter in the ratio of its *atomic weight*, while electric current passes through matter in the ratio of its *chemical valency*.

But matter has another relation to energy in the form called chemical affinity: in this aspect each order of combination of each kind of atom possesses its own energy, which bears no known relation to any others: this specific energy is a matter for experiment in each case (§ 253); but the energy given up in the act of combining (which may be measured either as heat or as electric action) bears an exact relation to what is called the affinity of the atoms forming that combination; to break it up we must apply a force equal to that affinity, and this fact means simply the law already mentioned, that in order to separate the atoms we must give back to them exactly the energy they parted with when uniting.

109. We may therefore conceive of substances as consisting of molecules built up of two parts, which are called *radicals* in chemistry and *ions* in Faraday's electrical nomenclature. There are many substances containing several radicals, but we are not concerned with them electrically, as only those substances which can form or break up into two radicals are electrolytes, or give passage to electric currents. These radicals may be similar atoms, as in metals, or they may be dissimilar atoms or radicals, as in salts: all that is to be attended to at present is the type or skeleton of matter as related to electricity, and the giving to this such a definite form as shall enable the actions to be understood. These two constituent radicals are variously named, as

+	−
Electro-positive	Electro-negative
Basylous	Chlorous
Cation	Anion
Basic	Acid
Such as	
Hydrogen	Chlorine
Metals	Sulphuric radical.

Various substances act as either radical, according to what they are united with, but in the electric current the radicals belonging to the first column turn towards the negative face or plate, and the second column towards the positive face or plate.

The two radicals are held together in a twofold manner:

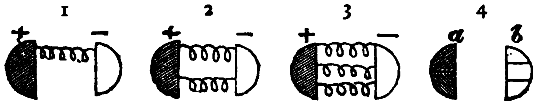
(1) By the valency of the radicals themselves: § 6. This constitutes the several classes of monobasic, bibasic acids, &c.

(2) By the specific energy of the individual substance.

Each of these bonds has a distinct electrical relation. The first governs what is called "quantity," and its actions; it constitutes what has been called the "equivalent of electricity," § 253. The second governs the tension needed to enable the current to pass when decomposition has to be effected, and is the basis of the old ideas of intensity. A purely mechanical representation will fix these ideas, but it must be remembered that this alone is its object, not to give a material conception of actual molecules.

Let us, then, typify the molecule as consisting of two parts held together by spiral springs; the *number* of the springs corresponding to the valency of the radicals, and the *strength* of the springs corresponding to the specific energy of the particular compound. We shall thus get:

Fig. 40.



But either the one or other of these single radicals may be replaced by separate atoms of single valency corresponding to one of Fig. 2 or 3, as shown in Fig. 4. Thus Type 1 represents the union of single monad atoms, such as metallic silver, Ag.Ag., hydrochloric acid, HCl, common salt, NaCl. Type 2 represents metallic copper, zinc, &c., and sulphates of those metals, $CuSO_4$, $ZnSO_4$. By regarding the + radical as composed of two distinct monads, as in 4 *a*, it represents the sulphate of sodium, Na_2SO_4, sulphuric acid, H_2SO_4, and corresponding substances; or by regarding the − radical as similarly divided, it includes the chlorides and nitrates of dyad metals, as zinc chloride, $ZnCl_2$. The same applies to all the other classes.

110. The atomic weights are purely relative; they apply to proportions only, whether grains or tons; but if we give them a fixed meaning these molecular types give us the most perfect possible unit of electric quantity and current. Let us consider the weight as taken in grains; then taking hydrogen 1 grain and 1 valency as our base, we have the unit of quantity as that necessary to set free from combination 1 grain weight of hydrogen or 1 atom of any monad, or to do equivalent work in any other atom; thus iron 56 grains, or zinc 65·2, would require two units of quantity to set them free, or would furnish two units themselves while

dissolving. To convert this into "current," time has to be taken into account, and for convenience of calculation I take ten hours. Then we measure electric currents by 1 grain of hydrogen, or equivalent action in ten hours. This unit, from its source I call a "chemic," and throughout this work this is what is meant by a unit of current, while the term unit of any substance means the quantity equivalent to this current as shown Col. VI. of Table XIII., § 253, for elements, and more generally in Col. V. Table V., § 167. The convenience and importance of these units will be seen in the facilities they give for estimating the work and cost of batteries.

111. The galvanic cell must be regarded for some reasons simply as a section of the conductor conveying the current; and as the first law of the circuit is that the "quantity," "current," or equivalent chemical action, is equal at every part of the circuit, the battery obeys this law. In each cell an electric equivalent of zinc is dissolved by an equivalent of acid for every equivalent of metal deposited, or other work done which requires a "quantity" equal to that of one unit or chemic current, no matter whether the action be fast or slow. "Quantity," then, means merely the equivalent of chemical action—the passage of energy along one of the chains of affinity, § 109. By this means we can calculate the cost of every kind of chemical or other work, knowing the rate of current to be maintained, and ascertaining the electromotive force needed to maintain it under the given conditions. For this purpose I have drawn up Table V., § 167, which is used in the calculations relative to the different cells.

112. The force generated by a chemical action depending on the degree of the affinity at work in that action, that generating substance is best which has the greatest attraction for the radical of the acid, but practical considerations limit us to iron and zinc as the cheapest; both, however, have the drawback that they maintain their action whether we want the force they can give us or no; but pure zinc is, however, very slightly acted on, except when the conducting circuit is closed, while ordinary zinc is continuously dissolved. The reason of this difference is by no means clearly known, though it is usually attributed to the presence of foreign metals, setting up little local circuits; and, therefore, this waste action, which contributes nothing towards the generation of current, is called "local action." It has been discovered that common zinc, when amalgamated with mercury, is not much acted on, and this seems to render this explanation somewhat doubtful. However, a well-amalgamated plate is scarcely acted on in dilute sulphuric acid, but the presence of nitric acid, or metallic salts, entirely does away with the protection, which appears to depend chiefly on the adhesion of a film of hydrogen gas to the surface, which prevents

contact with the liquid. When the circuit is closed the hydrogen is transferred to the negative plate, and the protection is removed, while the conditions of discharge bring fresh actions into play. Amalgamation also renders the zinc a better source of electricity, as it is more positive than ordinary metal. Zinc should always be well amalgamated for use in cells with acids; it is of less consequence in presence of saline solutions, and in Daniell's cells it is a disadvantage, § 131.

113. AMALGAMATION.—Care should be taken to use only pure mercury; much of that sold contains lead and tin, which are mischievous. The mercury should be kept for some time in a bottle, with dilute nitric acid over it, and occasionally shaken up. To amalgamate zinc, wash it first with strong soda, to remove grease; then dip it in a vessel of water containing one-tenth of sulphuric acid, and as soon as strong action takes place transfer it to a dish (such as a soup plate); pour mercury over it, and rub it well till a bright silver-like film forms; then set it up to drain on edge, and before use rub off any globules which are set free. Whenever the zinc shows a grey granular surface (or rather before this) brush it well and reamalgamate, remembering that saving of mercury is no economy, and free use of it no waste—for it may all be recovered with a little care. Keep a convenient-sized jar or vessel solely for washing zincs in, and brush into this the dirty grey powder which forms and is an amalgam of mercury with zinc, lead, tin, &c., and forms roughnesses which reduce the protection of amalgamation. This washing should be done whenever a plate is removed, and never less than once a day if in regular use; the fibre brushes sold at 3*d.* and 4*d.* as coarse nail-brushes are excellent for these purposes, but of course must not be left soaking with acids. Let the powder collect for a time and then transfer it to a bottle, in which wash it with sulphuric acid first, and then with dilute nitric acid, and you will recover the mercury; or the dried powder may be mixed with a little salt and distilled over from an iron retort into water.

114. Rolled zinc should always be used in preference to cast. The latter is very hard to amalgamate, and has less electromotive power, but for rods for use in porous jars, and particularly with saline solutions, cast zinc is very commonly used. In this case, great care should be taken to use good zinc cuttings, removing any parts with solder on them, and using a little nitre as a flux, which will remove a portion of the foreign metals.

Rolled sheet zinc, from one-sixteenth to a quarter-inch thick, suitable for cylinders and plates, costs about 4*d.* per pound. The simplest way to cut it to size is to scratch a groove with a steel point, such as a bradawl; run first acid solution, and then mercury along this groove, and allow it to penetrate; then repeat the process on the other side, when the metal is easily broken; it may also be cut with a handsaw. Zinc possesses a peculiar property of softening with a moderate heat, so that hard and brittle as the metal is, it can easily be bent up into small cylinders, if held in front of a good fire till too hot to handle with the naked hand, and then bent round a piece of wood or metal.

115. Sulphuric Acid.—This is the most important excitant used in ordinary batteries, and as it varies very much in quality and strength, it is desirable that its properties should be understood. Real O.V. oil of vitriol has a specific gravity of 1·845, and contains about 99 per cent. of the true acid (H_2SO_4); it is of a clear colour, and has an oily appearance: this is the acid always meant when sulphuric acid is spoken of. Brown oil of vitriol is the ordinary product of the chambers, or this boiled down in lead pans, and contains variable quantities of acid. This is a question of price only, but this acid often contains impurities of serious consequence.

Brown colour may be due to dissolved organic matter, straw, &c., and is of no moment.

Arsenic is often present, and must be strictly avoided, as it unites with the hydrogen given off, forming a deadly poison when strong, and being in any case injurious to health. It is detected by diluting the acid, and passing a stream of sulphuretted hydrogen: arsenic forms a yellow precipitate. Another plan is to put the dilute acid in a flask with scrap zinc, closing the flask with a cork in which is fitted a small glass tube bent at right angles; a Bunsen's gas-burner or spirit lamp is so placed as to make a part of this tube red hot; the gas carries off the arsenic and deposits it as a black film in the neighbourhood of this spot.

Lead is often present as sulphate, and must be carefully removed, or it will deposit on the negative metal; it is only necessary to dilute the acid in a separate vessel, allow it to cool, and filter it off before use.

Nitrous acid is often present and wastes the zinc, by destroying the hydrogen film, but is otherwise of no consequence. It is detected by mixing the acid in a test tube with two or three parts water; when cool drop in a crystal of sulphate of iron; if, as it dissolves, a brown colour is produced, there is nitrous acid present.

The strength of acid used in batteries may vary from one-twentieth to one-tenth by measure of acid to water.

Table II.—Specific Gravity of Sulphuric Acid.

One-twentieth	1·055	70 per cent.	1·598
One-tenth	1·100	80 „	1·708
One-third	1·259	90 „	1·807
50 per cent.	1·388	100 „	1·846
60 „	1·486		

The third line is that strength which has least resistance, and may be used in voltameters; all the following lines are percentages by weight. Very strong acid cannot be used in batteries, as there must be at least water enough to dissolve the sulphate of zinc as formed. A good solution is made by mixing 1 part by bulk with 10 of water, which should be soft, as water containing lime is apt to form a deposit on the metal surfaces; if hard, it should be boiled before use. 100 grains by measure of such a solution will dissolve about 11¼ grains of commercial zinc; but it is bad economy to nearly saturate the acid, particularly if several cells are combined in series, as zinc is then pretty sure to be deposited on the lower part of the negative plate, which is thus destroyed for the time, and from which, as the zinc is pure, it is a troublesome process to dissolve it. But, allowing for impurity in zinc, local action, and a due proportion, or about one-fifth of free acid left, one pint of this solution would dissolve about 1¾ oz. of zinc. We may thus calculate the work a cell is capable of doing as about equal for each pint of solution to 24 equivalents or units, and the cost per unit of the single acid cells (line 27, Table V.) ·0438 of a penny, taking amalgamated zinc at *6d.* per lb.

116. As a general rule cells are used which are too small, and little regard is paid in proportioning them to their work; this is no doubt due chiefly to a want of consideration of cause and effect, and to the work being seldom regarded as a definite quantity. It is impossible for a small cell to work regularly, because the liquid rapidly changes its nature. In double liquid cells care should be taken that the two are so proportioned as to contain the relative quantities of the two liquids required for the work to be done, so that neither is wasted; and Table V. will show what these quantities are. In some cases, for practical reasons, it is best for the elements to be in the form of plates, but in many cells they are cylinders; and then the question arises, which should be the outer one, the zinc or the negative? This question may be put in another form: if the plates differ in size, which should be largest? This has been a good deal discussed, owing to consideration being directed to only a portion of the subject. There are two good reasons why the negative metals should be largest. (1) The zinc is subject to local action, or waste, which contributes nothing to the work, and therefore its size should be reduced to just that amount which is requisite to maintain the current required. (2) The negative plate is subject to "polarization" or deposit of hydrogen upon it, and should therefore be as large as possible.

After a great many trials, I have come to the conclusion that the best arrangement is one in which the negative element is a cylinder fixed within the containing vessel, in the middle of which the zinc can be suspended. This is recommended purely on the foregoing practical reasons; theoretically there is no difference in the force, or resistance, whichever arrangement is adopted with cylinders: and the enlarged surface of a cylinder in great degree compensates as to resistance for its greater distance as compared with flat plates. Neither the size of the cell, or the size, form, or arrangement of the plates, has any relation to the electromotive force of the battery; this being a function only of the chemical action of the cell is the same with a pair of fine wires as with plates a yard square. But size has a great effect upon the *current* the cell can produce, as it is a great element of the resistance; but this effect is exactly the same as that produced when a long, fine wire is used for a conductor instead of a short thick one.

117. The simplest form of galvanic generator, and the one first devised, is the combination of alternate plates of copper and zinc. Most electrical works employ a good deal of space, and many figures, in describing the various forms devised by way of improvement, by Cruikshank, Wollaston, and others, consisting chiefly of the mode of arrangement in the containing vessels, the use of double copper-plates surrounding the zinc, and such like matters; the value of which has been entirely destroyed by further progress. But as the simple copper-zinc arrangement is the most unsatisfactory form known, it is wasting time and space to describe such modifications; this couple calls for attention simply for the sake of principles.

COPPER AND ZINC.—When first a pair of plates are immersed in dilute sulphuric acid, and the wires connected to a galvanometer, a considerable deflection is produced, marking a powerful current, but even in a few minutes the effect rapidly decreases.

After a short time the copper is seen to be covered by a dark film, which it is commonly stated is oxide of copper, and the other metals contained in it. This is erroneous, however, for it is evident that oxides could not possibly form in the presence of nascent hydrogen; it is really a combination of this hydrogen with the metal, and the diminishing power of the cell is due to the formation of this hydride or alloy, which prevents contact of the copper with the liquid, thereby increasing the internal resistance, while the affinity of the hydrogen for the acid radical resists the polarizing power of the zinc, and therefore diminishes the electromotive force of the couple or cell. See § 262.

Pure copper, as deposited by the electrotype process, has a higher power, probably because of its purity, but also on account of the nature of its surface, which is covered with innumerable fine points, from which the hydrogen is given off more readily than from a smooth surface. Hence, if a copper negative plate is to be used, it should have a deposit of copper formed on it. The rapid failure of power will be observed in Table IV., § 166.

118. IRON AND ZINC.—Iron has often been recommended as a negative element because its surface keeps clean. Its force is very low, as will be seen § 267; and also in the table of experiments, § 166. The reason of its surface remaining clean is mainly that the acid acts upon it as well as on the zinc, and thus causes much waste. Still, its cheapness may tempt some to use it; a very unwise economy. For this reason it should be stated, that wrought or rolled iron is alone fit for use, as the presence of carbon in cast iron sets up local actions.

119. LEAD has been recommended; but a glance at Table IV. will show its worthlessness.

120. SILVER AS NEGATIVE.—This acts very well, especially if a thickish deposit is formed upon a thin sheet, so as to obtain a rough surface. Such a coating may be deposited on copper, but deposited metal is always porous, and the acid is always found to act upon the copper; this is the only drawback to a plan often suggested, of making negatives of copper-wire gauze plated, which otherwise makes an excellent negative: it should never be left in the acid when out of action.

121. PLATINIZED SILVER.—Smee having assured himself that the nature of the surface was of the greatest importance, and that the hydrogen is more readily given off from a rough surface than a smooth one, and also bearing in mind that platinum has the highest electromotive force of all the metals as opposed to zinc, deposited this metal as a fine black powder on the surface of silver, and the cell with this as the negative plate, which justly bears his name, is one of the most valuable gifts ever made to electrical science. In its usual form it is of simple construction; the silver sheet is held in a saw-cut down the middle of the inside surfaces of a wooden frame, of which the top and bottom bars may be $\frac{3}{4}$ in. thick, and the sides $\frac{3}{8}$, the wood being well-baked and soaked in melted paraffin before putting together by the usual mortises and tenons; a sheet of zinc is held on each face by means of a brass clamp with a screw, which presses them against the frame, and carries also the binding screw for the connection, that for the silver passing through a hole in the top bar, and being soldered to the silver; the zincs should be narrower than the silver, in order to give free escape for the gas. For large works the sheet is frequently fixed upon a board, so as to use one side only, and is placed outside the zinc. In this case a very good mode of connecting the zincs is to have a narrow trough containing mercury across the bottom of the cell, connected by means of a wire covered with cement, so that merely standing the plate in the trough connects

the zinc at once, and also keeps up its amalgamation: a bar should be provided in the upper part of the cell for the zinc to lean against. Each zinc, for regular working, should be in the form of at least two plates; one of them can then be removed and replaced by a fresh plate without deranging the work going on.

Substitutes for silver have often been proposed, as copper, lead, and an alloy of lead, tin, and antimony; they are all wretchedly bad economy, and it should be remembered that the silver, even if a little costly at first, has an intrinsic value of its own, even when worn out. Rolled silver can be obtained ready platinized, or ordinary thin sheet can be lightly roughed with fine glass-paper, or by dipping in nitric acid, and the platinum deposited on it thus. Insert in a vessel with dilute acid, and connect it by a wire to a small slip of zinc in a porous vessel in the same acid; in fact, mount it as a battery, but exposing at first only a mere touch of the zinc to the liquid; drop in a few drops of platinic chloride, and stir; gradually a faint colour forms on the silver; add more platinum salt, and increase the zinc surface; and after a good adherent coat is formed, gradually increase the action till the surface is fairly covered with a black coating, which touch as little as possible. The platinum solution is made by dissolving scraps of thin platinum in a mixture of two parts of hydrochloric and one of nitric acids; the solution is very slow, and is best effected in a flask with a long neck, in which is inserted a test tube filled with water, and stood by in a warm place; it is not necessary to drive off acid or to crystallize for this use, as the free acids are of no consequence.

Even this cell, however, it will be seen §§ 262 and 267, rapidly fails in power, if worked with a full current, owing to adhesion of hydrogen.

122. CARBON AND ZINC.—Mr. Walker suggested the use of graphite plates, and has used them in batteries for telegraphic purposes; it has also been platinized, which increases its power. Owing to the greater resistance of carbon and its power of condensing hydrogen, this combination gives a lower current than a silver plate of the same size, and has various inconveniences which render it less economical in the end than silver. See § 145.

123. The usual form of any of these single liquid cells is that described for the Smee § 121, but except for the cost of the larger negative it is more advantageous to make this a cylinder as large as the jar will contain. For ordinary or occasional purposes the best mode of construction is to use a jar or a wide-mouthed bottle, and place the negative element in it as a fixed cylinder with wires coming from it to support it, which should be well covered with guttapercha or cement (§ 130), and to these a binding screw should

be fixed. The opening should then be closed with a piece of wood prepared by well baking and soaking with melted paraffin; in the middle should be a hole which will just permit the zinc plate or rod to be passed in when required; at other times this opening can be stopped to prevent evaporation.

124. A similar arrangement can also be made with a porous jar secured in the top, and this may contain a saline solution to diminish action on the zinc. In this case, there must be provided an opening in the top, outside the porous jar, for the purpose of changing the liquid and allowing gas to escape. If the part of the porous jar above the liquid be well stopped with paraffin, § 128 (or if merely a glass tube passes down to below the surface of the liquid), the cell in this form becomes an admirable voltameter, if a small tube is fixed in the top to which a caoutchouc tube can be added to carry the gas away to be measured. This construction is available also for use with a second liquid in contact with the negative plate, as the similar form described § 145 is available for use as a single liquid cell.

125. *Odds-and-ends Cell.*—Smee proposed what he called an "odds-and-ends" cell, composed of a jar in which a quantity of mercury was placed with scraps of zinc: broken plates, even raw spelter might be used by floating them in the mercury; a plate of platinized silver was then suspended in the jar and the acid solution added. This has been tried by many, but for many reasons has seldom given satisfaction. It is, however, well suited to operations requiring a continued current, as the chief objection is the great local action, especially when so constructed that platinum can fall on the zinc and mercury. The following modification, however, will be found useful for working up scrap zinc, as it can be inserted in the liquid just while required. Take a vessel, such as an old porous jar, and pierce its walls with holes, or make one of guttapercha, which is stronger; the lowest inch or so is not perforated, as it is to contain mercury, to the bottom of which is plunged a stout copper wire, amalgamated at its end, but covered everywhere else with gutta-percha, and cemented to the side of the vessel, reaching to its top, where it is to be soldered to a binding screw which is the zinc connection. All the rest of the surface is pierced with as many holes as possible, consistently with strength, to allow free circulation of liquid. It is then filled up with pieces of zinc, amalgamated and in as close contact as may be; the whole acts and is used just as if it were an ordinary plate. The mercury is subject to little waste, but now and then the whole should be removed, well shaken up together, and repacked, and at times the mercury as it becomes charged with metals should be filtered by squeezing through a wet chamois leather, the residue being preserved and added to the

collection described § 113. This zinc cell may be used either in any form of single acid cell, or in a Daniell or other cell, within a porous jar.

A porous cell similarly fitted and either with or without the holes, containing mercury in the bottom, may also be used in the bottle form described § 124; this allows all the connections of a battery to be arranged, and action set up at any moment by placing the loose zincs in the mercury; if desired, all the zincs can be attached or hung to a frame or bar, suspended over the battery and lowered all at once into their cells.

The cost of such a cell working with zinc, worth at most 3*d.* per lb., would be at most ·0284 of a penny per unit. For operations on a large scale, perhaps the best form is a cell like Fig. 42, § 130, one side charged with zinc sulphate, having a layer of mercury at the bottom for the scrap zinc, the other containing the silver plate and acid.

126. All the combinations described so far have two faults. (1) *Weakness.* Owing to the force being largely absorbed by the escaping hydrogen, their electromotive force is low, and any large resistance greatly reduces the current they can yield. (2) *Want of Constancy.* As shown by the rapid fall in the experiments, § 166, though this is in great degree overcome by largely increasing the negative surface. Constancy is a term frequently misunderstood; it does not imply that a cell shall work for a long time, as that depends mainly on its size and the quantity of excitant supplied to it; constancy means the furnishing of a steady equal current during the time for which the cell is at work.

127. TWO LIQUID CELLS.—For many purposes, constancy is essential, and it is desirable in all, hence continual efforts have been made to overcome these two defects, and with considerable success, though a really constant battery has yet to be discovered, notwithstanding the praises bestowed by manufacturers and patentees on several forms. As yet approximate constancy is only to be obtained by the use of two agents, one acting on the zinc, the other absorbing the hydrogen at the negative plate, and the success is greater just in proportion to the degree in which this negative plate and liquid can be kept in their normal condition, or at least, in an unchanged relation to conductivity and chemical action. Hence they all require a separating medium, as to which a few practical observations will be of value.

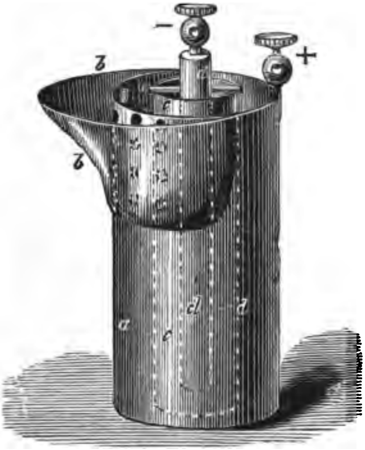
128. POROUS JARS.—At first, animal membranes, bladders, ox gullets, &c., were employed. In some cases good paper is useful. In experiments requiring great resistance, glass tubes plugged with plaster of Paris, or even clay, are employed; for small experiments, or for platinizing silver, the bowl of a tobacco pipe may be used. For practical purposes, however, unglazed earthenware is the only

material of any service, and it is now to be obtained in any form and size. There are many qualities, and they must be adapted to the special purpose. These porous jars act only by the liquid they absorb, and as they very greatly reduce the area of liquid through which the action takes place, of course they greatly increase the internal resistance, and diminish the action (§ 232); on the other hand, there is no possibility of preventing some mixture of the two solutions thus separated, and this causes waste by local action besides affecting the regularity of the actions. Hence for long-sustained action a thick and close-grained jar must be used, while an open and more porous one suits best for short periods and strong action. The most porous ones are of a red colour and soft material, the finest and most enduring are close-grained and white; a good material is soft and may be scraped with a knife. The best test is to fill them with water and see how long it is before it forms a dew on the outer surface, if it runs off the jar is not fit for use. It is a great improvement to render the bottom, and still more the part which is to remain above the liquid, non-absorbent. If this is not done the salts rise up, effloresce, crystallize, and disintegrate the jar. For the same reason jars taken out of the liquids must not be permitted to dry, but should be kept soaking in water to prevent their destruction. This is of particular importance with jars used for the Daniell's cell, as they are very apt to get nodules of copper deposited on them wherever the zinc has touched the inner surface, and particularly at the bottom, where drops of mercury or flakes of zinc fall, and then the cell is very soon rendered worthless; if this occurs, the spot of metal should have some cement or guttapercha laid over it, so as to render it non-conducting. Some porous jars are glazed at the upper part; when this is not the case they should be rendered non-absorbent by standing in a thin layer of paraffin kept just above its melting point, till this has been soaked up as far as is required.

129. The Daniell's Cell.—This, the first devised improvement, is also the most successful attempt to obtain constancy. To it also we owe the discovery of the electrotype process, and all it has grown into. Its principle is, that copper, as the negative metal, is surrounded by a solution of a salt of copper, which is reduced; instead of hydrogen, copper is set free, and it is deposited on the negative surface, which is thus kept constantly renewed. The acid of the salt is transferred by electrolysis to the positive metal, through the porous medium, hence if a fresh supply of the salt is added to the solution to replace that removed, this part of the arrangement remains constantly in the same condition; but still absolute constancy cannot be obtained, because as the zinc dissolves, the solution belonging to it becomes less active and less conducting. The great drawback to this cell is that the copper salt passes by

endosmose into the zinc solution, and acts on the zinc where the copper is deposited, and causes great waste by setting up local actions. It is to diminish this that a great variety of forms have been suggested, known by the names of the proposers and patentees, some of which are described below. A plan I have found to answer with large cells for long-continued experiments in which constancy was important, is to use a larger porous jar outside the zinc one, filling the space between them with a strong solution of zinc sulphate, and some zinc cuttings to decompose any copper salt entering; the inner cell is thus kept nearly free, but of course the internal resistance is somewhat increased. The ordinary form of the Daniell is shown Fig. 41, *a* the copper vessel fitted with a reservoir *b* for the crystals, *c* the porous cell, *d* the zinc rod suspended in it by a bar passing through it. The part of the copper cylinder within the reservoir is of course perforated. Modes of construction may be varied to any extent. Thus instead of a copper containing vessel, a glass or earthen jar may be used with a cylinder of sheet copper, or such a jar may be covered inside with a film of wax, blackleaded, and the deposited copper will form its own surface, but the first is the best plan, especially as the sulphate of copper has a great tendency to climb up glass surfaces, on which it crystallizes and finds its way by degrees to the outside.

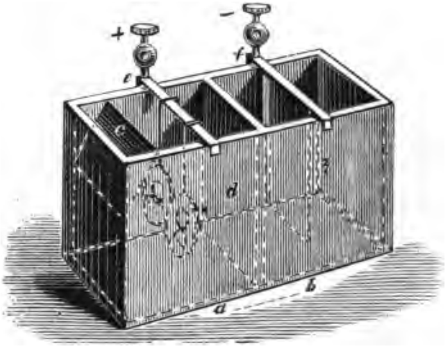
FIG. 41.



130. Instead of cylinders, flat plates may be used in a vessel across which a plate of porous material is fixed, and this form has several advantages, among others it is easy to make the cell itself serve as a depositing vessel by using models, seals, &c., in fact any object we wish to copy, as the negative surface, by suspending these to a rod which forms the + pole of the battery. This is in fact what is called the single-cell process of electrotyping. In this case the cell is best made of wood, lined with a resinous cement; guttapercha may be used, but has the disadvantage of facilitating the *creeping* process of acids and salts, which is troublesome and messy, besides causing loss of power by establishing paths by which the force escapes. Four parts resin melted with one of gutta-

percha, and a small quantity of boiled oil, answers perfectly; the wood should be perfectly dry and warm when it is applied.* Such an apparatus is shown in Fig. 42; *a b* is the box divided by the porous partition *d*; *c* is a place for holding the crystals; *e* and *f* are two bars of metal, to which are hung the objects to be copied and the zinc plate, and each is fitted with the necessary binding screw. The bars being movable, it is easy to regulate the distances, and so to control the action, by altering the internal resistance.

FIG. 42.



This apparatus answers admirably for a voltameter by using a light copper plate and weighing it after the conclusion of an experiment. (§ 190.)

Instead of a fixed porous partition a flat porous cell may be used to contain the zincs, so as to have copper on both sides. In this and in other cases a convenient connection to the zincs is a bar of wood crossing the cell with a deep channel in it to contain mercury or a row of mercury cups let in it, all connected by stout copper wires to a binding screw at the end of the bar; the zincs have a stout copper wire soldered to or cast in the upper end, and this is bent over so as to dip in the mercury, and allow the zinc to be instantly removed and exchanged.

The Daniell cell will serve as an approximate measurer of current by the solution of the crystals. As these contain one-fourth their weight of copper the quantity needed for a given work is easily calculated, and if this is put in the reservoir, when dissolved it will indicate the completion of the work; for instance, if we desire to deposit a plate of copper of a certain weight, when about four times that weight of crystals is dissolved the proper deposit will be made; any kind of work may be similarly reckoned by means of the Equivalent system and Chemic unit of current.

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* A similar cement with a larger proportion of guttapercha may be used for covering wires, first heating them so as to ensure adherence; for this purpose it should be run into sticks.

Many of the telegraph lines are worked by Daniell's cells, fitted with plates in cells, either divided by a fixed plate or the zinc contained in a flat cell, only the side of which facing the copper is left porous, the others being smeared with tallow, &c., to diminish endosmose. Several of these are mounted in one box, provided with binding screws for making the necessary connections.

Instead of a porous plate dividing the cell permanently into two parts a row of common porous cells may be used, so that the zinc may be partially removed for cleaning, &c., one at a time, without much affecting the current; such cells may also be distributed about among a number of plates or objects, in order to secure equal distribution of the action.

131. The fluid surrounding the zinc may be the usual acid, or where rapid action is not needed, common salt, or sal ammoniac, and other substances are used, or for telegraph purposes, pure water; in these cases the zinc need not be amalgamated, which has this advantage, that any copper reduced on it does not combine, but causes less local action, and is more easily removed, by means of a hard brush. The local action in this case is only that due to this endosmotic salt, but when acid is used a much greater waste is caused, as the copper on the zinc sets up local circuits, and causes the acid also to act upon the zinc; it is also more difficult to remove the copper as the reduced metal is fixed by the mercury. The best solution to use when constancy is desired is a half saturated one of sulphate of zinc, which is kept in proper condition by occasionally removing a little and replacing with water. When a battery is required only at intervals, the zinc solution should be emptied into a jar with a few scraps of zinc to reduce any copper; excess of zinc should not be added, as zinc has the little known property of acting upon its own sulphate and producing an insoluble basic salt, which however redissolves on heating with a little free sulphuric acid.

132. The theory of the action of the sulphate of copper cell is easily explained as an extension of that shown Fig. 39, § 101. If we consider the two molecules to the right of the porous partition to be sulphate of copper,

$$\begin{array}{l c|c|c|c}
\text{We have,} & & \overbrace{H_2SO_4}, \ \overbrace{H_2SO_4} & \overbrace{CuSO_4}, \ \overbrace{CuSO_4}, & \\
\text{polarized} & \text{Zinc} & \overbrace{SO_4H_2}, \ \overbrace{SO_4H_2} & \overbrace{SO^4Cu}, \ \overbrace{SO^4Cu} & \text{Copper.} \\
\text{breaking up} & & \overbrace{ZnSO_4}, \ \overbrace{H_2SO^4}, & \overbrace{H_2SO_4}, \ \overbrace{CuSO^4}, Cu &
\end{array}$$

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The last line shows that what occurs is that an atom of zinc is taken up and one of copper displaced, that the source of the force is simply the difference between the affinity of sulphuric radical for zinc and copper; the acid serves only as a conductor, as it will be seen that there is the same quantity after action as before; the force yielded is equivalent to the heat zinc would give while precipitating copper from its sulphate, and is really the difference between the internal force necessary to the existence of sulphate of copper, and that bound or latent in sulphate of zinc. It is probable also that it is only at the last molecule that copper sulphate forms part of the circuit if there is free acid present, but that does not affect the principle, which explains the action more comprehensively than the idea that water, or even acid, is decomposed, and completes the circuit, while the nascent hydrogen merely reduces the copper chemically. (See also Fig. 68, § 281.)

133. This form has been fully examined because of its importance, both practical and theoretical, and it only remains now to show the cost of its working. In this instance, this is shown in full detail, and will serve to show how the cost of the other forms has been arrived at in Table VI. § 168.

The local action will depend on the quality of the porous vessel, rate of working, &c., but we may allow 5 per cent. We have then per unit, by Table V. § 167,

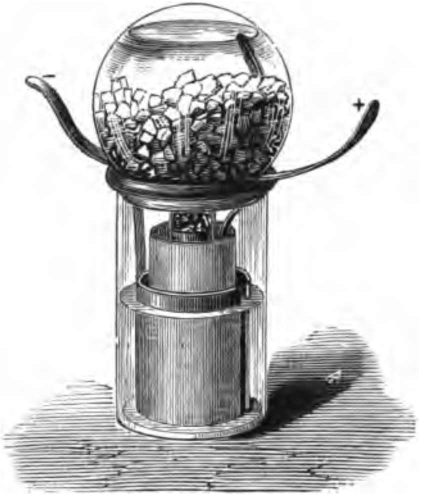
Line 24	Zinc unamalgamated	·0195
„ 9	Copper Sulphate	·0900
	Local action	·0055
		·1150
„ 8	Copper	·0566
	of a penny ..	·0584

This assumes that zinc sulphate is used in the zinc cell and costs nothing, it being a product of the working. The reduced copper is taken at the common value, but if it is deposited in useful forms the actual cost of the cell will be reduced to nothing in many cases.

134. **Meidenger Cell.**—This is a modified Daniell with the copper cylinder inside and a reservoir of crystals in a flask, as there is no capacity for it in the cell. The flask is closed with a perforated cork, fitted with a glass tube, which dips below the surface of liquid in the cell, and keeps up the supply on the principle of the bird fountain. Such a cell furnishes a small constant current for a great length of time, but is of course liable

to great local action unless the work is regular and adjusted to the rate of solution of the salt.

Fig. 43.



135. A similar arrangement is sometimes used without a porous cell, and with the copper arranged as a flat plate at the bottom of the jar; the principle is that the dense solution of the copper salt flows slowly out and spreads over the copper in a thin film which is reduced before it rises, provided the rate of flow is just balanced to the work of the cell. For this purpose a funnel filled with crystals may be used in place of the flask and a loose cover used to prevent too great evaporation: the zinc may be a ring or plate suspended in the liquid at a height such as to remove it from too ready access of the copper salt. This is of course a modification of the principle of the Gravity Battery, § 157.

136. The Minotto has been much lauded; it consists of a jar, at the bottom of which is a copper plate, fitted with a wire, this is covered with an inch of crushed sulphate of copper, and this again with a layer of silver sand which is to act as the porous division. Some use sawdust instead of sand, others paper pulp, or felt, and each of these gives the name of its proposer or patentee, to what is a mere form of the Daniell, and all are liable to its defects; they are useful for some purposes in which a great internal resistance is not an objection, but the copper inevitably finds its way to the zinc.

137. **Callaud's Gravity Cell** resembles these last in form, but trusts only to the greater specific gravity of the solution of copper sulphate and its slow solubility, to protect the zinc. The bottom of the jar is covered with a sheet of copper fitted with a wire conductor, upon this is laid a stratum of crystals of copper sulphate, which should be large if a small current is wanted, small when much work is to be done; the zinc plate is suspended above and the jar charged with water, or a weak solution of sulphate of zinc; it must of course be placed where subject to no vibrations or disturbance, and has been much used on account of its inexpensive construction in the telegraphs, especially in France and America, but has been little used for other purposes.

138. **Spiral Battery.**—A form of the gravity battery has been patented lately which claims as its principle the separation of different liquids by means of a kind of repulsion set up by the electric current. The negative element consists of a stout wire wound in a flat helix, which occupies a position about the middle of the vessel, the wire then descends from the middle of this, either in a straight line or a spiral, and forms another helix spreading over the bottom of the vessel, from which it rises in a guttapercha tube to the top of the vessel, terminating with a binding screw. A tube or funnel may occupy the middle of the vessel and contain a supply of crystals, and the zinc is a plate suspended in the upper part; it is claimed that the copper salt will not rise above the copper spiral. A similar arrangement is used with a current passed into it as a separator of liquids. All the turns of the wire are to be in the same direction, so that all the parts of the current are parallel.

139. The next great class of generators includes those which employ at the negative plate some substance containing oxygen in a state to be readily given up. The ingenuity of inventors has been much exercised in devising variations of (1) the negative plate, (2) the oxidizing agent, this latter being either liquid or solid. The principles and qualities of the many different forms will be much better understood by keeping this classification in view, than by a mere description of particular forms.

140. **Grove's Cell.**—This was the first devised, and is for many purposes the best of its class; the negative is platinum, which is usually employed too thin in order to save in first cost; the form is not essential, but it is usually a flat plate, which ought to be corrugated vertically as this enables a large surface to be exposed and makes the plate stiff; this is placed in a narrow flat porous vessel to contain the excitant, nitric acid, in quantity suited to the work. The zinc may be a couple of plates, or a single plate bent so as to surround the porous jar at a distance of $\frac{3}{8}$ths of an inch.

Fig. 44 shows this cell in section, and will serve for many of its modifications.

FIG. 44.

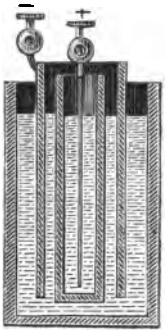
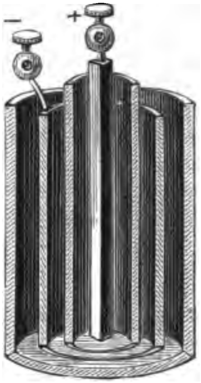


FIG. 45.



141. **BUNSEN'S CELL** is the same, with some form of graphite, usually gas carbon, employed in place of the platinum of Grove's. It also may be in the form of a plate, but is more commonly a solid block in a cylindrical porous jar, as in Fig. 45, which will serve as the type of the circular forms.

142. **CARBONS.**—The employment of carbon is attended with some difficulties which call for attention. Carbon is one of the most remarkable of the elements, possessing what is called "allotropic" forms, § 8, in which, though chemically the same thing, its physical properties are different, with different relations to heat, electricity, and light; such varieties are the diamond, charcoal, and graphite. It is this latter which is useful in electricity, either in its natural form of plumbago or blacklead, or the artificial deposit of gas carbon. It must be clearly understood that this substance is *not coke;* coke is the solid residue left after distilling coal; the graphite comes from the *gas*, the rich hydrocarbons of which are decomposed by contact with the heated retort, on which they form a shell; it is, in fact, a great nuisance to the gas maker, as it arises from the destruction of the richest gas, injures the retorts and wastes the heat; in the gas works it is called "scurfing." The densest and hardest is the best for electrical use; it should be almost non-absorbent, and ring like a metal when struck, and have a clear grey colour, not black. It is rather costly when good, because of the great difficulty of working it.

The best mode of cutting carbon is that employed by stonecutters, by means of a piece of iron, sharp silver sand, and water; important elements of the process are time and labour, for the material, if good, is very hard to work.

143. The chief difficulty with carbon is making the connection with it; this is commonly done by simply fixing a clamp on it, in which case a piece of platinum ought to be interposed between the two surfaces. A better plan is to deposit copper on the upper part, and then solder the connection to it, as this gives continuous circuit; the copper takes on it just as it would on a metal. There is one drawback to this, the same in fact which requires the platinum interposed in the first plan; the acid both creeps up the surface and soaks into the substance, and then acts on the copper and destroys the connection. The following plan, however, I have found a perfect protection against this. Heat the end of the carbon, and touch the part just beyond where the copper is to extend to (which should be about half an inch from the end) with a piece of paraffin, taking care it does not run up the part to be deposited on; should it do so, it may, however, be driven off by strong heat; when cold, cut a few scores in the surface to give a hold to the copper, and drill a hole through, in which fix firmly a copper wire projecting on each side; now, with a warm iron, spread a good film of paraffin from the line of the intended coppering as far down the carbon as the part to be immersed in the liquid of the battery when working. Connect a wire to the carbon by a screw clamp, and insert in a copper solution, arranging at first for a quick deposit to prevent entrance of moisture into the pores of the carbon. When a good deposit is made, drill a few holes right through copper and carbon, soak in water to remove any absorbed copper salt, and dry it thoroughly. Now tin the part to which the binding screw or connecting wire is to be soldered, and stand the carbon with its coppered part in a vessel of melted paraffin, just as described § 128, till its upper part is well saturated, the holes being intended to ensure this. When the connection is soldered a coating of paraffin may be spread with an iron over the copper, and all parts of the carbon not intended to be acted on by the liquid. No cement is of any use for this purpose, paraffin alone resists powerful oxidants, such as nitric acid, and it is equally a protective against caustic alkalies.

144. Artificial Carbons.—Plates or blocks may be built up from powdered graphite mixed up with coal tar or strong rice paste, into a stiff dough, which should be dried, heated, then packed in powdered carbon in a closed vessel and heated to clear red for some time. When cool they should be soaked in strong syrup of sugar or treacle, again dried and treated as before: this process must be repeated until the carbon is perfectly dense and

strong. In this way are made cylindrical vessels, left somewhat porous to hold the acid and act the twofold part of porous jar and negative plate; many of the plates and blocks in batteries of French make are thus made, and work fairly well, but under some chemical reagents they break up.

Battery plates, &c., are also made of plumbago crucible material, but this soon disintegrates. Faure's Battery is made of this material in exactly the form of a ginger-beer bottle, this contains the acid under a pressure caused by the gases given off, which are retained by means of a graphite stopper ground in, which also serves for the connection of the cell, being fitted with a binding screw.

145. **Composite Graphite Battery.**—A very convenient cell may be built up on the system described § 124. In the middle of a jar stand a porous cell, and outside this, one or more strips of carbon prepared as § 143: then pack the space well with pieces of broken graphite, cover with a ring of wood or pasteboard prepared with paraffin, with apertures cut in it for the carbons to pass through, and fitted with a large tube for supply of liquid, and a smaller on the opposite side to allow air to enter and gas to escape: on the top of this run in any cement, such as resin and brickdust, to secure the whole. In this and in all cases where cement is intended to adhere to glass or earthenware, these should be first warmed up to a point just enough to melt the cement when rubbed over the surface.

This cell may be used with any liquids, it does not polarize quickly on account of its large negative surface, therefore it is pretty constant, but it has considerable resistance owing to the imperfect conducting power of the carbon when thus merely in contact.*

146. **Iron, &c.**—Other materials have been employed, as lead or iron. Cast iron has been strongly advocated under the name of Callan's, or the Maynooth cell; a very few words will sum up their qualities. They are worthless. If anyone wishes to lose his temper and his money he can use an iron cell with every prospect of success. They waste the acid, which at some unexpected moment boils over; in fact they have every evil quality without

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* The conducting power of carbon is much below that of metals, and unlike them it rises with the temperature. Matthiessen gives the following values compared with silver as 100:

Purified Ceylon graphite	0·0693
Gas coke	0·0386
Bunsen's battery coke	0·0246

It is sometimes used as a resistance measure, small glass tubes being filled with powdered graphite. Mr. Phillips has likewise devised a measure for very high resistances, made by drawing lead-pencil lines upon ebonite and other suitable surfaces.

one redeeming point. The force is only three-fourths of carbon, so it requires four of them to give a current equal to that of three Grove's and Bunsen's; and as the iron is acted upon, this, and the equivalent of the costly nitric acid, is wasted.

147. It is difficult to state exactly the reactions which take place in the nitric acid cell, as they are continually varying with the strength of the acid. HNO_3 may lose one atom of oxygen, becoming HNO_2 nitrous acid, under two units of action which provide H_2 to form H_2O water: but one atom of hydrogen is equally able to take up one of oxygen together with the hydrogen of the acid; thus $HNO_3 + H$ becomes $H_2O + NO_2$; or the same reaction taking place with the residue (nitrous acid) of the first case, $HNO_2 + H$ becomes $H_2O + NO$. In each of these cases the work done electrically, by one atom of acid would be different. The principal action which really occurs is the first and third combined, $HNO_3 + H_3$ becoming $2H_2O + NO$, and according to this, one atom of nitric acid is effective for one and a half equivalents of electrical action; or to express it practically, though not in the true chemical language, two-thirds of an atom is the equivalent. This action is, however, complicated with others, for the acid is even totally deoxidized and converted into ammonia to some slight extent. Owing to this and to the loss by evaporation or carrying away of acid by the escaping gases, and by leakage through the porous cell, and the impossibility of exhausting the acid, the full atom HNO_3 must be regarded as the equivalent. Hence the cost of working is ·1570 of a penny.

The internal resistance is very low, so does not waste much energy. It also diminishes during the first part of the action while the gases are being absorbed by the acid.

148. Strength of Nitric Acid.—When we buy nitric acid we only get a solution of it, varying very much in actual strength. The following table shows the strengths of different qualities and the quantities of each representing an electric equivalent.

Table III.—Nitric Acid.

	Specific Gravity.	Percentage HNO_3.	Atoms per lb.	Atom in 1000 liquid grains.
1	1·5210	100·	111·11	21·4
2	1·4518	77·777	86·42	17·90
3	1·4200	70·000	77·78	15·78
4	1·4000	66·	73·	14·49
5	1·3945	64·156	71·28	14·19
6	1·3732	60·437	67·15	13·17
7	1·2402	38·121	42·36	7·51

1, is the absolute theoretical acid, called the 1st hydrate formerly.

2, is $2HNO + 2H_2O$, formerly the 2nd hydrate.

3, is $2HNO_3 + 3H_2O$. This is the strength to which boiling brings both stronger and weaker acids and distils unchanged at 248° Fahr.

4, is the strength taken in the table, § 167.

6, and thereabouts, is *double aquafortis*, and about 7 is *single aquafortis*.

149. **Saline Solutions** are sometimes used in the zinc cell, but this is bad economy, as it results in the solution of the zinc being really affected by the nitric acid, of which therefore double quantity is used. But such solutions, and preferably a half saturated solution of zinc sulphate may be used if the equivalent proportion of sulphuric acid be added to the nitric acid in the porous cell. An acid is sold at a low price under the name of dipping acid, which contains a good deal of sulphuric acid, and this may be advantageously employed in the porous cells.

150. **Alkaline Nitrates.**—Several of the variations of the nitric acid cell are based on the use of the nitrates of soda or potash in place of nitric acid; nitrate of ammonia, even, has been employed, but it is expensive and has no sort of compensating advantage. When a solution of these nitrates is mixed with sulphuric acid, a reaction takes place by which the base is divided between the two acids in ratios depending on the relative proportions present; hence results a solution containing a proportion of free nitric acid which acts in the usual manner, while the remaining nitric acid is only set free as the action of the battery proceeds. Nitrate of soda is the best, it is cheaper by the pound, its equivalent is lower, and therefore the pound does more work, and it is very much more soluble, and therefore a much more active solution is obtained. It is not, however, generally known that water when fully saturated with one of these salts will still dissolve nearly as much of the other as though it were pure water, and thus the strongest solution is made by dissolving both the salts together. With nitrate of soda at 2*d*. per lb., the cost of the atom of nitric acid obtained from it in the cell is ·0456, against ·1096 of the acid itself at 8*d*. per lb., but while this latter contains 14·5 units in 1000 fluid grains, the nitrate of soda solution would contain about 6·5, and therefore require much larger porous cells. But the great drawback is that it gives less force, as may be seen § 268, and the internal resistance is much greater than with nitric acid.

151. **Slater's Iron Cell.**—In almost all the forms of battery iron may be used in place of zinc for the dissolving metal, but owing to its lower electromotive force, and other practical reasons, it is seldom employed; however, Mr. Slater has introduced a form

of cell in which iron as the negative metal is combined with the use of nitrates as the oxidizing agent, and which may be of use where it can be so placed that the fumes from it are not injurious, for though less than in other cases, these are still given off, and render it objectionable in a confined space.

Its construction needs no detailed description, as its only difference from the Bunsen is the substitution of iron for zinc, a plate or block of carbon being in the porous cell, which, in this case, ought to be of large dimensions. The solution is nitrate of soda, saturated at 100° Fahr., and 2 equivalents of sulphuric acid added for 1 of salt dissolved, which brings the specific gravity to about 1568. On cooling, a quantity of sulphate of soda crystallizes out.

At starting, the outer cell is charged with water, to which is added a small proportion of the solution to render it conducting, and set up the action, which is then kept up by electrolysis and by endosmose, though it is to be observed that the liquid passes somewhat rapidly into the inner cell, the liquid in which stands at a considerably higher level than in the outer; the action is maintained by removing a portion of the inner liquid at times, and adding fresh solution, so that there is little waste. The power of this cell is considerable, and its cost ·1086 of a penny per unit.

152. **Bichromate of Potash.**—In order to overcome the nuisance of nitrous fumes, various substances yielding oxygen have been substituted, and this is one of the most commonly employed. Its price varies from 8*d.* to 1*s.* per lb., according to that of potash. It is not a true twofold acid salt, like bisulphate of potash, and its formula is variously written as K_2O2CrO_3, or $K_2Cr_2O_7$, making its atomic weight on the new notation 295·2. Four atoms of sulphuric acid (98 × 4 = 392) unite with this, and the result of the reaction when effected in a battery and completed, is the production of chrome alum, and 3 atoms of oxygen, the abstraction of which, by the nascent hydrogen set free by the reaction of 3 more atoms of acid upon zinc, is the cause of the action considered apart from the preliminary action of the sulphuric acid on the salt itself, which does not affect the ultimate result. Thus omitting the extra water required for the alum,

$$\begin{array}{cccccccc} K_2Cr_2O_7 & + & 4H_2SO_4 & = & \overline{2KCr2SO_4} & + & 4H_2O & + \\ 295 & & 392 & & 567 & & 72 & \\ 3Zn & + & 3H_2SO_4 & = & 3ZnSO_4 & + & & \\ 165 & & 294 & & 483 & & & \end{array} \left.\begin{array}{r} 3O \\ 48 \\ 3H_2 \\ 6 \end{array}\right\} 3H^2O.$$

In this notation, O = 16, and the electrical unit of oxygen being 8, this quantity of salt is equal to 6 units; that is to say, its own equivalent or unit is 49·2; or for convenience, and to allow for impurity, say 50, which quantity requires 66 by weight, or 38 by measure, of sulphuric acid to effect its own decomposition; if in the same solution is to be provided the acid to act on the zinc, an additional equivalent is needed, making the quantity for each unit of work 115 grains by weight, or 66 by measure.

Owing to the insolubility of the salt, the solution is weak, a pint being only about 25 units, therefore a large porous cell must be used, unless, as is better, the zinc is placed within. The usual directions for preparing the solution are to dissolve 3 ounces of the salt in a pint of water by aid of heat, and when cool, add one-twelfth its bulk, or 2 ounces of sulphuric acid, but this is erroneous; it only supplies the first 4 equivalents of acid, and though given for single cell bichromates, is only suitable for a double cell, in which acid is used besides to dissolve the zinc. In order to utilize the salt completely, a nearly equal quantity of acid should be added, when the action becomes sluggish; if added at first it causes too great local action, and this is always very great.

In a double fluid cell, the best plan is to add of acid one-seventh of the bulk of saturated solution, and to use the sulphate of zinc solution with the zinc. The resulting chrome alum is generally thrown away, though it is a valuable salt in dyeing. It is a nuisance in the battery, as it crystallizes upon the carbons and in the cells; if saved it must be left to evaporate spontaneously, as heating the solution spoils it.

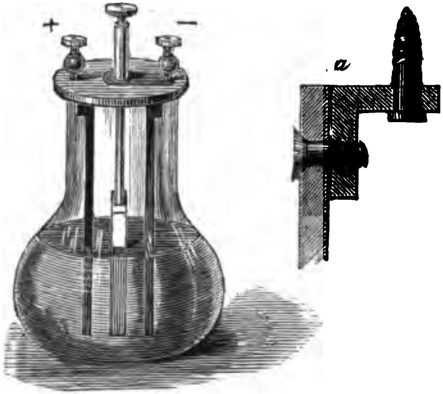
One thousand fluid grains of saturated solution at 62° Fahr. contain 2·16 units of salt, and require 83 or 143 fluid grains of sulphuric acid, according to the plan adopted. The cost of working as a two liquid cell is ·1320 of a penny per unit.

153. Nitric Acid with Bichromate of Potash has been highly spoken of by some writers as giving a constant current and no fumes. It is quite true that the constancy of the current is much improved, but after a little time the fumes are given off; the reaction is simply the reoxidation by the bichromate of the reduced nitric acid. Still this plan is useful where a strong current is required for a given time, as for producing the electric light. The solution recommended is a saturated solution of bichromate in nitric acid, with one-third volume of sulphuric acid added, and just enough water to redissolve any chromic acid precipitated.

154. Bichromate Single Cell.—This consists of two plates of carbon, with one of zinc between them, fitted so that it can be raised out of the liquid. Of late many of the shops have small bichromate cells without this fitting, the intention being to let the cells go on working to exhaustion; it is therefore desirable to warn readers against using such cells, which are most extravagant and unsatisfactory. Used for the purposes to which it is suited, the bichromate cell is one of the most useful; it furnishes a most

powerful current for a very short time, it is therefore admirably adapted for short experiments with induction coils, as it gives a greater force than the nitric acid batteries, and has no unpleasant fumes, while it can be set aside for weeks and be ready for action at any instant. But for long-sustained action it is utterly useless, as its force fails very fast. The simple action of raising and lowering the zinc, however, instantly restores it. The reason of this is that there is no circulation in the liquid, owing to no gas coming off, and the motion of the zinc stirs the liquid up. Thus by setting up the battery in a thin glass vessel to which heat can be applied by a gas burner, I have maintained the current in full even flow until the whole liquid was exhausted. Many plans have been tried to remedy this defect, especially by French makers, as Grenet's plan of forcing in a stream of air in small bubbles, so as to keep the liquid in active circulation; others cause the liquid itself to circulate through several cells. But the ordinary form will be most generally useful, as shown in Fig. 46.

FIG. 46.



The containing vessel is usually a glass bottle enlarged into a globe below; the object is merely to hold a larger quantity of liquid, and any form of vessel will answer. The essential part is the top which carries the plate; this is best made of ebonite, but hard baked wood saturated with paraffin will do; in the centre of this is screwed a projecting brass tube split at the top to grip the rod carrying the zinc which slides in it: the foot of this tube also passes through a plate of brass extending on one side of the cover to the negative binding screw. This sliding part is often troublesome, as the surfaces tarnish and make bad contact; they should be well gilt to avoid this, and some attach an open spiral of wire to the lower part of the rod and to the tube, so as to make a fixed metallic circuit independent of the sliding one; others attach the binding screw to the top of the sliding rod. It is desirable to form a screw thread on the top of the tube, and fit to it a nut, by tightening which contact is improved, and the zinc firmly held up when not in action; also a square tube and rod are better than round ones, as they keep the zinc always parallel with the carbons. The zinc is commonly fixed to the rod by means of a screw on the end, but it is far better to solder them together. I was once greatly troubled with an irregular battery, which would not keep to its work, though I pulled it to pieces and set everything right, as it appeared, and after great trouble traced the whole fault to this point; acid had found its way into the thread of the screw and entirely destroyed the connection. The carbons are secured to the cover by means of two angle pieces or brackets of brass or iron, as shown (*a*, Fig. 46), and these brackets are connected to the + binding screw. The connection is thus one of simple contact, and with a porous carbon it is common for acid to find its way up between the surfaces and destroy the contact. This may be entirely remedied by the plan described in § 143; and the upper part of the carbon being coppered the bracket may be soldered to it, and perfect connection ensured, and protected by a covering of paraffin.

It is impossible to estimate the cost of working this cell, because the local action in it is so great, and this being nearly constant while the zinc is immersed, or when frequently removed, its proportion to the work actually done will be less as this is greater, greatest that is when there is great resistance; for the average of working it is probable that the cost may be taken as ·2000, or half as much again as given in § 152.

A very convenient form of this cell is used as a battery and commutator combined, for such purposes as bells and other appliances requiring a momentary current; the zinc and its rod is supported by a spring, spiral or otherwise, and is pressed into the liquid when the current is required; on relieving the pressure the zinc leaves the liquid, and cuts off the current.

155. **Delaurier's Cell.**—This is a modification of the bichromate; its purpose is simply to obtain a somewhat stronger solution for the porous cell; the larger cell itself, and plates, with other details of construction, are mere matters of arrangement, and equally applicable to other solutions. All the remarks made as to the bichromate cell apply equally to this; its force is the same as nearly as possible, so also is its rapidly failing current. The

added salts add nothing to the work; they only take oxygen from the bichromate and reserve it in a more soluble form.

The solution consists of 300 parts water, 54 bichromate of potash, 45 sulphate of iron, 50 sulphate of soda, and 94 by measure of sulphuric acid, added in the order given.

The cost per unit is ·1971 and 1000 grains contain about 2·7 units, instead of 2·16 with the simple bichromate solution, so that the small advantage gained of the solution lasting a little longer is obtained by increasing the cost over one-third.

For use in the single cell the proportions vary somewhat from the above, but the result is the same.

156. CHROMATE OF CALCIUM, FITZGERALD AND MOLLOY'S CELL.—This form, lately introduced, is likely to become an important electrical instrument. There is a particular construction adapted to high resistances, in which the carbon plate serves the double purpose of a diaphragm and the element, but the principal matter is the substitution of the chromate of calcium for the bichromate of potash; lime being cheaper than potash, the salt can be sold at a cheaper rate and without fluctuation in price. Its constitution is $CaCrO_4 = 156$, but it also contains 1 atom of water, and allowing for 3 per cent. impurity its weight becomes 180; and as this gives 3 equivalents of oxygen, the electric equivalent is 60; the price is taken at 7*d*., but it would probably be 6*d*. when regularly made for a considerable demand, as may arise if the salt is used, as it probably will, as an oxidant upon a large scale in the arts, to replace the potash salt.

When mixed with the due proportion of sulphuric acid part of the calcium is thrown down as sulphate of lime, leaving dihydrochromate of calcium in solution, which gives up the rest of its base as the action goes on; this salt being more soluble than the bichromate of potash the action of the cell is more prolonged, and the solution has the great advantage of not crystallizing.

The electromotive force is the same as that of pure chromic acid, and the greatest of any known excitant, varying from 2 volts to 2·07, according to qualities of the carbon.

The reaction is

$$3Zn + 2CaCrO_4 + 8H_2SO_4 =$$
$$3ZnSO_4 + Cr_2 3SO_4 + 2CaSO_4.$$

This represents 6 units of work, and therefore the cost is ·1240 of a penny per unit.

One of the great features of this cell when used on the large scale is that the products have a value which would reduce this cost greatly, as the residuary solutions can be readily converted into various valuable chrome colours.

The cell itself is arranged to give a large negative surface by using a series of carbon plates mounted in a ring of lead, forming the cover of the cell, and surrounding the porous cell for the zinc in the middle; it is of course available for use with other excitants, such as the bichromate of potash, or as a single acid cell if desired, as the enlarged surface considerably increases the action as compared with other forms.

157. IRON PERCHLORIDE.—This has been employed in batteries; its action consists in undergoing a reduction to ferrous chloride, and the object aimed at was the regeneration of this by absorbing oxygen from the air, so as to maintain an inexhaustible oxidant. It has the same drawback as the bichromate battery in rapid failure, and its force is also low: there are, however, cases in which such a combination might be useful, and it will form a single cell with iron as positive, and work to exhaustion if free acid enough is occasionally added and the excess of liquid removed.

Peroxide of Iron might be employed for similar reasons, instead of and in the same way as the manganese peroxide § 158, but it gives only just half the force of the latter.

158. PEROXIDE OF MANGANESE BATTERY.—Various peroxides have been employed to surround the negative plate and furnish the oxygen. Peroxide of lead is the most powerful of all, and consequently a battery in which this is used gives a very high electromotive force; but it is costly, and has never been used except experimentally, and the peroxide of manganese is the only one of these substances practically useful. Its employment was first suggested by De la Rive, many years ago, but the difficulties which soon present themselves to those who use it have prevented it coming into common use; on the other hand, it has many good qualities, which have led recently to its quiet appropriation by several trading makers, and it has been patented under the name of "Leclanché" cell. For cases requiring a large current, as in plating, or for magnets or coils, it is absolutely useless; for a small occasional current, on the other hand, as for ringing bells, household signals, &c., it is one of the most useful forms; though the statement made by sellers that the cell is calculated to work for "three years" is, of course, pure nonsense. Like every other form it can yield a current equivalent only to the quantity of material used in it, which will be exhausted in a greater or less time according to the work done. Its duration depends upon two things—the quantity of the excitant and the quantity of the manganese.

The work any manganese cell can do will probably be to furnish one unit of current for each 150 grains of manganese put in it.

The peroxide of manganese, otherwise binoxide, is on the atomic notation, $MnO_2 = 87$; two of these atoms enter into the reaction producing Mn_2O_3 sesquioxide of manganese, and O one atom of oxygen; and, as this oxygen is 16, while our electric unit is 8, it follows that the atom of peroxide is also the unit, as 87 of it by weight yields this 8 of oxygen; but this is the pure substance, while the commercial manganese contains often a large percentage of impurity, so that 100 is about the unit: in addition to this, as no solution occurs, the action takes place only on the surface of the particles into which the material is divided, and hence a considerable portion may escape action; it is therefore impossible to fix upon any quantity as the electric unit; it may range from 100 to 200 grains or more. The peroxide is a good conductor; the resulting sesquioxide is not a conductor (and the same is the case with the corresponding lead oxides), hence the action tends to diminish: and a main object must be to spread the material in as thin a film as possible over a large area of conducting surface. This is most readily accomplished by crushing carbon into various sizes, from a pea down, and packing the larger pieces tightly in a porous jar, in layers, so that the particles are in firm contact among themselves, and with a plate or bar of carbon, which forms the main plate or conductor; the finer grains should be mixed with three times their bulk of manganese also in fine grains and sifted in among the network of large pieces: the fine powder has to be sifted out, because it resists the penetration of the liquid. The result of this arrangement is to expose a very large surface which compensates for the inherent slowness of the action itself, and reduces the internal resistance.

A very small surface of zinc is sufficient, and it generally is one or two small cast rods or rolled strips suspended in the outer vessel.

This is the usual arrangement, but it is far better to reverse it, and put the zinc inside the porous vessel, making the battery up exactly as described § 145, with the manganese added as above.

159. The Excitant.—Either common salt or sal ammoniac is employed, though others will answer. It may at first sight seem difficult to say why sal ammoniac at *6d.* per lb. should be used if common salt at 3 lb. per penny will answer; but as a couple of ounces of the chloride of ammonium will charge a cell, such as the ordinary Leclanché, and do the amount of work for which alone it is properly fitted for several months, the question of economy dwindles to a very small matter against the higher electromotive force the ammonium chloride gives over that furnished by the sodium chloride. The reason for this higher electromotive force is, that soda displaces ammonia from its salts, and, of course, in doing so loses force; therefore, when they are decomposed the sodium salt has less to yield. In the one case, caustic soda is

generated within the porous cell; in the other, ammonia is set free and given off, while the soda remaining exerts a counter electromotive force. The force is greatly increased by occasionally adding a little acid to the manganese cell to neutralize the alkali.

I have found the electromotive force at first starting to be with

Sal ammoniac	1·543	volts.
Sulphate of ammonia	1·493	„
Common salt	1·285	„

Ammonium chloride forms double salts with zinc chloride, and also with hydrated zinc oxide, and the latter compound appears in the form of crystals upon the zinc and porous cells. The crystals have the formula ZnO, H_2O, NH_4Cl. As they obstruct the action they should be removed with warm water containing a little acid, but they do not form so readily if a half saturated solution is used.

The cost of the manganese cell is probably ·25 of a penny per unit for materials, but this is the least consideration because the trouble of charging is the real cost.

As various modifications of the manganese cell are claimed by various patentees, it may be as well to distinguish them.

The *Leclanché*.—Manganese with carbon in a porous cell closed with pitch. Sal ammoniac the excitant.

Grenet's Cell.—The same with a bag substituted for the porous pot, and common salt as the excitant.

Highton's Cell.—The same with various acids added occasionally to the manganese to absorb the ammonia.

There are also slight modifications of form, which are however merely matters of construction and first cost.

160. **Sulphate of Lead Battery.**—In this we leave the principle of supplying oxygen at the negative plate, but we have an insoluble matter there. It has several forms. Originally the porous cell was filled up with the sulphate surrounding a metallic or carbon plate or rod; a patented modification consists of a stout copper wire, to which are fixed several saucers, also of copper, tinned, for holding the metallic salt and preventing its solidifying in the porous cell, so that it may readily be replaced. This is, no doubt, a great improvement, though it is very doubtful whether the sulphate of lead battery is worth improving, as its electromotive force is low and its cost considerable, being ·1738 of a penny per unit.

As the cell has the merit of very fair constancy, and yields a large current for some time, it might be useful for some purposes if the residuary lead generated were used for its metal. It would work better with sulphate of zinc than with salt, because salt dissolves the sulphate and carries lead to the zinc; it also under-goes a curious reaction by which sodium, set free nascent, appears to react upon a part of the sulphate and generate a sulphide.

161. **The Sulphate of Mercury Cell.**—This, which is called from its inventor, the Marie Davy Cell, is of use only in circumstances requiring a small intermittent current of great force; thus, as it gives no trouble, requires no care, and gives off no unpleasant fumes, it is very useful for domestic telegraphs, &c., but it is quite useless for employments requiring large quantity. Originally, it consisted of a porous cell, with a rod of carbon packed with the mercury salt; then the porous cell was abandoned, and a peculiar arrangement employed, in which the carbon was at the bottom of the vessel; but now it is usually a simple zinc and carbon pair, the latter of which extends to the bottom of the vessel and dips into a mass of the sulphate. The vessel is then charged with water, which dissolves a small portion of the salt slowly, and this sustains the action, the acid radical acting on the zinc, the mercury depositing on the carbon, from which it falls and collects as metal at the bottom. The action can, therefore, only be sustained at the slow rate at which the salt enters into solution.

There are two sulphates of mercury. The proper one is what used to be called the bisulphate, now the mercuric sulphate $HgSO_4$, with the atomic weight 296. It is obtained by heating in an evaporating dish two parts by weight of mercury with five to six of the strongest sulphuric acid until only a dry white powder is left. The cost of working is, allowing for the reduced mercury at 3*s.* per lb., ·5337 of a penny per unit, which is very high; but for the special purposes for which alone the cell is useful this is of little consequence, being compensated by the steadiness and convenience of the cell, which, unlike the manganese cell, is easily replenished.

162. **Clark's Mercury Cell.**—This is proposed by Mr. Latimer Clark, not as a working cell, but as a standard of electromotive force, to compare with other cells by means of condensers or electroscopes, it having a constant electromotive force of 1·457 volts. It consists of a layer of pure mercury as the negative plate, connected by means of a platinum wire in a glass tube. On this is laid a paste of mercurous sulphate, which has been boiled in a thoroughly saturated solution of zinc sulphate; the positive element is a plate of pure zinc resting on the paste. According to this, which is Mr. Clark's own description, the sulphate used in his cell is not the same as that employed in that last described, but the two are so commonly confused, owing to the changes in the atomic weights, &c., made of late years, that I cannot say that this is really the case.

163. **Chloride of Silver Cell.**—This is a wire or plate of silver, upon which chloride of silver has been melted as a coating

of "horn silver;" it is used in a solution of zinc chloride, and is employed mainly to work small pocket coils for medical purposes.

But the chloride may be used as a powder, in the same way as the sulphate of mercury in the Marie Davy, or it may be mixed with powdered graphite, and used in a porous cell with a plate of carbon. As chloride of silver is produced on the large scale in refining and other metallurgical operations, and has to be reduced for the sake of its metal, it would appear that where it can be obtained at a trifle less than the value of the silver it contains, a very economical and powerful battery might be thus produced.

164. There are many other forms of the galvanic cell; many useless; most mere modifications or forms of those described. Others have great scientific interest, but do not come within the objects of the present work. Such is Grove's gas cell, in which oxygen and hydrogen are in contact with platinum plates dipping in an acid solution which separates the gases, and act the part of the metals while recombining as water; this is, in fact, the voltameter reversed, and a voltameter with separate receptacles whose plates project above the liquid, will, when the decomposing current is cut off, act in turn as an electromotor and give up, in the form of a galvanic current, the energy employed in setting the gases free. There are very many forms of this principle, such as those which act by absorbing oxygen from the air; of these, one of the most interesting is that proposed by Messrs. Gladstone and Tribe, who have made so much use of the electrolytic action upon substances of a copper zinc couple, formed by zinc on which pulverulent copper is precipitated from the sulphate. When silver and copper are connected in a solution of copper nitrate well aërated, the copper dissolves and cupreous oxide is deposited on the silver; a similar action occurs in a solution of zinc chloride with zinc and copper. The negative metal is arranged as a tray near the surface, perforated in many places and containing also crumpled masses of the metal in foil rising above the liquid to facilitate absorption of oxygen. In fact, every chemical reaction which takes place among substances which conduct electricity can be made to serve as an electromotor. For instance, if caustic soda or carbonate of soda is placed in a cell separated by a porous diaphragm from another containing an acid, they unite through the pores; and if a plate of platinum or of carbon be inserted in each cell, the combination forms a galvanic generator having a force equivalent to the chemical affinities acting, § 250. This completely disposes of the theory lately revived, that the electromotive force is set up by the contact of different metals, § 259, for there is no such contact present; but the fact is that the chemical affinity alone supplies and measures exactly the electromotive force. This is also shown by the fact, that in a copper and iron pair, iron is the positive metal in acids

because it dissolves; but in sulphide of potassium, which dissolves copper, the copper is the positive metal. A similar reaction has been lately used by Mr. Fleming to illustrate this. Cells containing nitric acid are arranged alternately with cells containing sodium pentasulphide, and the cells are connected alternately with bent strips of lead and copper; in the acid lead is positive to copper, and in the sulphide it is negative; so that a battery is composed, in which there is no contact of metals, and the terminal cells contain the same metal, which, being copper, gives also no contact of dissimilar metals when the copper conductors from a galvanometer are connected. The combination is said to have one-fourth the force of a similar number of Daniell cells. It is not available for practical purposes, but has much theoretical and scientific interest.

A plate of zinc and one of copper, or a bag of coke buried a little apart in moist earth, has been used under the name of an earth battery, for driving clocks. This is its only use, and as it has a low force and high resistance, all that can be said in its favour is that, once mounted, it is out of the way and requires no attention; but any ordinary small cell will do as much work.

165. **Arrangement of Batteries.**—The laws which govern the mode of arrangement of a number of cells, in order to effect most work, will be found, §§ 244–6.

In joining cells, care should be taken not to waste energy in the connections; all points of contact should be as large as possible, and be kept perfectly clean. This is often neglected in mounting batteries, particularly in Grove's cells, where the platinum is bent over and screwed to the next zinc; in all such cases the metal should be fixed to a thick plate of brass, so as to screw firmly to the zinc.

The connecting wires should be of good size; and, in order to give some elasticity, should be wound in a spiral upon a small rod.

Care should be taken that the troughs, boards, &c., are quite dry, and that there has been no leakage or creeping of liquids from the cells, which causes short circuits and great loss of power. To avoid this, the jars should not stand directly upon a board; but a good plan is, to place two strips of varnished glass edgeways along the troughs or stands, for the cells to be placed on. There is a convenient apparatus made for this purpose in America, for use in telegraph offices; it is a flat saucer with ribs upon its inner surface, and a funnel opening from its middle. A series of these can be arranged in holes upon a shelf or board, with arrangements below to catch any drip; the cells stand upon the ribs, and are consequently very completely insulated. The following figures by Mr. Nigner, F.R.A.S., show the effects of care, and exhibit also the power of the electric light.

Each line represents the light in candles given by 60 cells, under the different conditions, the size of the platinums being 5 × 2¼ inches:

As commonly arranged	1860
With zincs carefully filed, &c.	2930
Insulated on glass rods, &c.	5360

166. **Work and Constancy of Cells.**—Table IV. gives a series of experiments on cells, all in like conditions; with plates 2 × 1 inches, set 1 inch apart, and with no external resistance, except that of a tangent galvanometer. The first column refers to the § in which the battery is described. The currents are given in chemics, and therefore are proportional. In the cells with porous division, it will be seen the current rises at first as the liquids soak in; in these cells, also, the current is reduced by the resistance of this division as compared with the single liquid cells.

TABLE IV.—WORK AND CONSTANCY OF CELLS.

Sec.		Minutes.				Hours.	
		1.	5.	15.	30	1.	2.
117	Copper zinc	5·2	4·2	3·8	3·5	3·2	3·
118	Iron „	2·9	2·	1·7	..	..	..
119	Lead „	4·9	0·5	..	..	..	..
121	Platinized silver	17·7	13·7	11·	9·	7·3	6·4
129	Daniell's	6·8	6·9	7·2	..	7·1	7·
141	Bunsen's	12·	..	..	13·	13·1	12·
151	Slater's	7·8	7·3	7·	6·8	5·9	4·2
152	Bichromate	7·3	7·8	7·3	7·	4·	2·1
154	„ Single cell ..	12·	10·6	9·4	8·4	3·8	1·1

167. Table V. contains a list of the principal substances used in electrical operations, arranged to accord with the unit of "quantity" and of "current" used in this work, and explained § 110, p. 85, showing the amount of each required to act with the unit of electric quantity and current. The weight (Col. IV.) allows for the ordinary impurities always present in commercial articles, and applies to good commercial materials not intentionally adulterated. The price (Col. VI.) is such as the substances can be obtained at in the ordinary way (with the exception of the silver salts), and where a different price is paid the user can readily apply a correction to the unit cost (Col. VII.) in any calculations.

Under the French system such a table would be far more useful than our wretched confusion of weights and measures allows it to be, as the figures obtained for the small units would apply equally to the largest amounts used in practice, while in the English system one calculation is needed to convert grains into pounds, and then another to ascertain the cost of these larger quantities.

TABLE V.—SUBSTANCES USED IN ELECTRIC WORKING.

I. Name.	II. Atomic Weight.	III. Valency.	IV. Commercial Equivalent.	V. Equivalents per lb.	VI. Price per lb.		VII. Cost per unit.
			grains.		*s.*	*d.*	*d.*
1. Acid hydrochloric	36·5	1	113	61	0	2	·0326
„ „ liquid	..		85				
2. „ nitric	63	1	96	73	0	8	·1096
„ „ liquid	..		69				
3. „ sulphuric	98	2	50	140	0	1½	·0107
„ „ liquid	..		28				
4. Ammonia	17	1	48	148	0	9	·0608
„ liquid	..		55				
5. Ammonium chloride	53·5	1	56	125	0	6	·0480
6. „ sulphate	132	2	70	100	0	3	·0300
7. Calcium chromate	349	2	60	116	0	7	·0604
8. Copper	63·5	2	33	212	1	0	·0566
9. „ sulphate	249·5	2	126	55	0	5	·0900
10. Iron	56	2	30	232	0	2	·0086
11. „ sulphate	278	2	145	48	0	2	·0414
12. Lead sulphate	303	2	159	44	0	6	·1363
13. Manganese, peroxide	87	..	100	70	0	4	·0572
14. Mercury	200	2	100	70	4	0	·6857
15. Mercuric sulphate	296	2	150	46	4	0	1·0285
16. Potassium cyanide	65	1	100	70	3	0	·5144
17. „ bichromate	295	2	50	140	0	10	·0715
18. Silver	108	1	108	64	135	6	16·4062
19. „ chloride	143·5	1	144	48	80	0	20·0000
20. „ cyanide	134	1	134	52	80	0	18·5000
21. „ nitrate	170	1	172	40	60	0	17·6914
22. Sodium, chloride	585	1	60	116	0	0½	·0043
23. „ nitrate	85	1	87	80	0	2	·0249
24. Zinc	65	2	34	201	0	4	·0195
25. „ amalgamated	..	..	..	..	0	6	·0292
26. „ sulphate	287	2	148	47	0	3	·0634
27. „ and H_2SO_4 cell	..	..	365	..	..		·0438

1. HYDROCHLORIC ACID.—Variable in strength; good quality is of sp. gr. 1·16, and contains about 32 per cent. HCl.

2. NITRIC ACID.—This varies greatly through the various qualities sold as nitric acid, aquafortis—double and single, dipping acid, &c. The highest strength has a sp. gr. 1·5; ordinary good commercial is about 1·390 to 1·420, and contains from 65 to 75 per cent. HNO_3. I have taken the acid at 1·400, and as equal to 70 per cent. See § 148.

3. SULPHURIC ACID.—This means concentrated oil of vitriol, sp. gr. 1·845, which is obtainable nearly pure.

4. AMMONIA, sp. gr. ·880, contains 36 per cent. NH_3.

16. POTASSIUM CYANIDE.—This is the white, which varies in quality from about 50 per cent. to 75, the highest which can be made; as the process involves the production of a proportion of cyanate. The quality is taken as 65 per cent.

18 to 20.—The SILVER SALTS are calculated as if made, allowing for labour, the silver being taken at 6*s.* per ounce troy. The cyanide is supposed to be simply precipitated and washed, not dried, and reckoned at 5*s.* per ounce. The chloride has an extra charge on it to pay for separation and fusion for use in batteries, and is therefore at the same price as the cyanide. The chloride ought to be obtainable 3*d.* per unit cheaper, in fact at its worth in silver,—that is, at 68*s.* per lb. —as it is a product in silver working, and has to be reduced for the sake of its metal. Nitrate of silver may be bought at 3*s.* 9*d.* per ounce, the price in the table. The cyanide should never be purchased, as it ought not to be dried.

168. **COST OF BATTERY WORKING.**—The value and mode of using the table of costs will be seen from the use made of it in the estimate of cost of working of the cells, § 133. These costs, however, are those of one unit of chemical *quantity* which is the equivalent of one chemic current kept up for ten hours. To ascertain the actual and relative costs in a form which permits comparison, we must include the consideration of the force produced and required to overcome the resistance; for supposing one nitric acid cell is required to do the work at a certain rate, it would require three Smee's to effect the same. The true mode of estimating the relative cost of different forms of cell is to reckon it, not per unit of current, but per equivolt of energy, which unites the two elements, § 257. This is obtained simply by dividing the cost per unit by the electromotive force (§ 264), and shows the relative cost for equal work done; even this does not take into consideration the element of internal resistance, which is largely dependent upon the relative size of the cells. Another consideration which cannot be reckoned is the relative convenience of management, such as is afforded by the single liquid cells by dispensing with porous vessels. Table VI. shows the relative costs thus calculated in both systems.

TABLE VI.—COST OF BATTERY WORKING.

Section.	Cell.	Cost per Unit, penny.	E. M. F. Volts.	Cost per Equivolt.
117	Copper zinc	0·0438	0·28	0·1564
121	Smee	0·0438	0·50	0·0876
125	„ odds and ends	0·0284	0·50	0·0568
129	Daniell's	0·0584	1·08	0·0541
140	Nitric acid	0·1570	1·6	0·0981
151	Slater's iron	0·1086	1·1	0·0987
152	Bichromate	0·1320	2·03	0·0651
154	„ single cell.. ..	0·2000	..	0·0985
156	Lime chromate	0·1240	2·	0·0620
158	Manganese	0·2494	1·5	0·1663
160	Lead sulphate	0·1738	·57	0·3049
161	Marie Davy	0·5337	1·52	0·3502
163	Silver chloride	0·200	1·2	0·0168
	„ or § 157.. ..	3·623	..	3·0318

169. The question is frequently asked what is the best battery? The foregoing description will show that no such thing exists, but that each form has its special qualities fitting it for particular operations. The following classification will assist in the selection.

TABLE VII.—SUITABILITY OF CELLS.

1. NAMES OF BATTERIES.

1. Smee.
2. Daniell.
3. Nitric acid.
4. Slater's iron.
5. Bichromate.
6. „ single cell.
7. Lime chromate.
8. Manganese.
9. Lead sulphate.
10. Mercury sulphate.
11. Silver chloride.
12. Magneto-electric machines.

2. USES CELLS ARE SUITED FOR.—*Large Currents.*—

Continuous.	
Electro deposition	2, 1, 7, 3, 5
Gilding	2, 1
Silvering	2, 1, 7, 3, 4
Electro magnets	7, 3, 4, 1, 2
Electric light	3, 7, 4
Temporary.	
Induction coils	6, 7, 5, 3
Medical coils	6, 1, 7, 5
„ „ pocket	11, 10, 8
Small Currents and High Resistance.	
Large telegraphs	2, 7, 8, 10, 12
Occasional.	
Domestic bells and telegraphs ..	8, 10, 9, 1
Exploding fuzes	12, 8
Testing resistances, &c.	7, 5, 8

CHAPTER V.

MEASUREMENT.

170. **Measurement by Magnetism.**—It has been already remarked that there are three modes of ascertaining the strength of a galvanic current, viz. by its magnetic, its chemical, and its heating powers; of these the first is the most convenient, because it interferes very little with the actual passage or work of the current, and is open to inspection at any instant, and thus gives full information as to any fluctuations which may occur. Instruments for this purpose are called galvanometers. They are based on the principle that a magnetic needle tends to place itself at right angles with a galvanic current. The reason of this is to be found in § 80. If *over* a magnetic needle at rest, and in the same direction, we place a wire, and through it pass a current entering at the southern end, the needle turns with the N. end to the left, or westerly; if the wire be *below*, the needle turns to the right. If the direction of the current is reversed, that is, if it enters at the N. end, the actions are reversed.

If the wire makes a turn round the length of the needle, it is evident all these conditions come into play at once, for the current entering at S. and passing *above* the needle, when the wire turns to the lower side, the current passes from the N., hence both the actions are the same and the needle is deflected to the left with double force; each turn has a similar action, varying, however, in its amount with its distance from and position as regards the needle. Hence the reaction of such a galvanometer is very complicated and can only be thoroughly traced out by elaborate calculations of little interest, except to pure mathematicians.

The practical result is, however, that no definite value can be given to the deflections of an ordinary galvanometer by any means except direct measurement. People are apt to think only of the degrees of the deflection, and suppose a deflection of 60° to be double that of 30°, which is entirely erroneous. There are only two forms of galvanometer whose readings can be at once valued, as they are related in one to the tangent, and in the other to the sine of the angles of deflection, but even this is only relative, and one galvanometer can only be compared with another by an actual measurement.

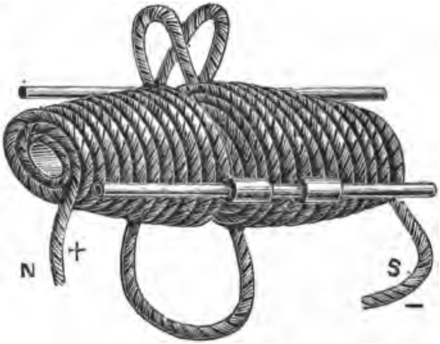
The galvanometer described § 180 was devised in order to take advantage of all the relations of currents and magnets and to express all the desired information in definite and comprehensible terms.

171. Galvanometer Needles.—These are frequently made too heavy; the heavier they are the greater is their "moment of inertia," and the force required to move them, and the longer they are in coming to rest. The best material is watch or clock spring softened, in order to shape and arrange it, then hardened by heating to red heat and plunging in water.

Long needles have most directive force and give more decided indications, but take longer in coming to rest; they are therefore best adapted to vertical galvanometers. Short needles are less affected by external magnetic disturbances and come quicker to rest.

Magnetizing may be effected by placing or rubbing on the poles of a permanent magnet. Fig. 47 is an apparatus which will be found very convenient.

Fig. 47.



It is simply a coil 3 in. long, of silk covered wire, No. 20, wound on an oval cardboard core, and the numbers of layers increasing to the middle; it is divided into two, and fitted with tubes on each part to slide over brass rods, and the wire is joined in the middle by a flexible metal cord to allow the two parts to slide apart; this allows double or astatic needles to be magnetized, by slipping each in turn into the coil, and passing a current from a bichromate or other powerful cell; a few seconds are sufficient, and with this apparatus it is no trouble to magnetize needles at any moment. Having ascertained which end of the wire gives N polarity to that end of the needle, it should be marked as shown, and always so connected; there will then be no confusion as to the direction in which the needles are being magnetized, and this is important, as the south end requires to be the heaviest before it is magnetized in order to balance afterwards.

Suspension.—For delicate instruments, the only satisfactory suspension is by a silk fibre, or such a thread of silk as may be drawn from a ribbon; hairs are sometimes used, but they offer a strong resistance to motion. The fibre should be attached at its upper end to a sliding rod (in good instruments a compound screw is used) which lifts without twisting the fibre. For ordinary instruments with a single needle, an agate centre fixed above the needle is used. Double needles may be suspended in a similar manner; the agate centre is first fixed in a thin brass tube by turning the edges lightly over it, the upper needle is then attached to it, if double by placing one part on each side, if single either by a hole opened in the middle or by doubling over the top and bringing down on each side so as to grip the tube firmly, and then touching lightly with solder, or an indicator may be similarly fixed. The lower needle is made of two pieces of watch spring, one fixed on each side of a very thin light tube, the sides of which are filed away to receive it, the ends of the needles are then to be drawn together and soldered or riveted. The tube should be under $\frac{1}{4}$ inch in bore and fit firmly upon or in the upper tube carrying the agate, and when the two needles are exactly adjusted a touch of solder will fix the tubes together, or, if preferred, the junction may be made by screwing. To adjust the needles, a suspension point is placed upon a movable board having a line marked upon it; one needle being magnetized the line on the board can be placed true N. or S., and the other needle or indicator being added, the tubes are moved slightly till the united system is correct.

The Swings of the Needle correspond to those of a pendulum, § 98, and for the same needle always occupy the same time; this gives a means of adjusting astatic needles to the desired delicacy and also of controlling the movements, for which see § 216. The number of vibrations of a needle may be diminished or arrested by *damping* in various ways.

(1) A plate of copper close to the needle, either as the dial plate or as the internal frame of the coils, checks the swings by the induced electric currents set up in the copper.

(2) A vane of paper or mica may be attached either to the needle or indicator.

(3) A similar vane may be attached to the bottom of the wire

which connects the needle to its fibre, to work in a chamber under the coils; sometimes this chamber contains mercury or some liquid, such as glycerine and water, the effect of which is to cause the needle to move slowly up to its point of rest without swinging; or the chamber within the coils may be so used.

Indicators may be made of a thin, hard drawn wire, aluminum being best, or of a thread of black glass, which may be drawn out over a Bunsen's burner or spirit lamp, by heating a small rod or tube (such as a bugle) to fusion, and drawing the two ends rapidly but steadily away. A more correct indicator, having no weight, is obtained by attaching to the suspending wire a mirror made of a circle of microscope glass silvered, upon which a ray of light is allowed to fall from a shaded lamp placed upon the continuation of the zero line of the instrument. The mirror is attached to the wire, or in Thomson's reflecting galvanometer, to one of the needles, by shellac varnish, or by a cement such as coaguline.

172. Astatic Needles are a pair of needles fixed upon a wire or a tube, as above described, with their poles in opposite directions, so as nearly to neutralize each other; if perfectly adjusted they would have no tendency to assume any position whatever; when very closely adjusted they do place themselves magnetic E. and W., but this is owing to the practical impossibility of fixing the needles in exactly the same vertical and parallel horizontal planes. In practice it is necessary to make one of the needles so much more powerful than the other as to bring the system to rest upon the zero line; the upper needle if made longer does this by its greater "moment."

173. Magnetic Intensity.—The actual strength of the needle's magnetism has no effect upon the deflection except indirectly by the relative effect of the resistances of the support; two exactly similar needles will be alike deflected, though one be strongly and the other weakly magnetized. The reason is that the needle is affected by two forces, the effort of the current and the earth's magnetic field, and these are equally reacted on by the needle itself. This applies only to single horizontal needles. A compound pair will deflect differently when strongly and weakly magnetized. A needle vertically suspended, and whose resistance to motion is caused by the excess of weight in the lower part, will also deflect further if strong than if weak. Different needles, if different in length, will also be differently deflected by the same instrument and current.

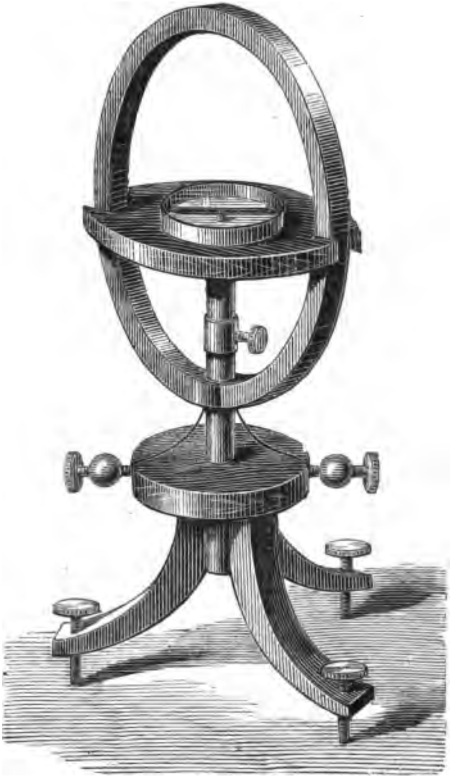
174. Stand for Galvanometers.—There is often some trouble in arranging instruments so that the needle stands directly upon the N. or S. or zero line, and many good galvanometers are made movable on an axis for this purpose. A revolving stand is, however,

a great convenience for a variety of purposes. The base should be of well-seasoned wood, and fitted with three levelling screws, and with a truly vertical axis rising from its centre. Upon this revolves a somewhat smaller disc, which may advantageously be carried by small wheels between the two boards. At opposite ends of one diameter there should be set screws to hold the disc steady when adjusted. The connections may be made to the instruments direct, but it is an advantage not to have these connections moved about, and therefore to make them to the stand itself. The binding screws for this purpose should be on the edge of the lower disc, and connected by stout wires to well-gilt springs, one on each side of the axis, working in recesses cut in the wood. The lower side of the upper disc should have upon it a round block of ebonite, carrying on its surface two gilt or platinum rings insulated from each other (upon which the lower springs are to press), and these are to be connected by wires let into the ebonite with two binding screws on the upper disc, or two flexible wires, by which connection is made to the instruments placed upon the stand, which may then be moved as necessary, without interference with any connecting wires. By marking the edge of one of the discs in degrees of a circle and attaching a pointer or vernier to the other, this stand converts any form of galvanometer into a sine galvanometer. § 177.

175. **The Tangent Galvanometer** is the simplest of the ordinary forms which give results capable of real measurement. Its mathematical explanation is given in most text-books; here it is sufficient to state the principle. It is that if a magnetic needle is placed at the centre of a circular electric current, to whose diameter it bears a very small ratio, the tangents of the angles of its deflections will be exactly proportional to the quantity of electricity circulating. The larger the circle and the shorter the needle, the more absolutely true this is; however, a needle 1 inch long in a circle of 1 foot diameter is correct for all ordinary purposes. In some instruments a wire is wound spirally upon a cone, the apex of which is the point of movement of the needle; sometimes a coil is placed on each side of the needle, with power of altering the distance.

The instrument may be solidly built on its stand, but it is far better (as indeed it is with all galvanometers, unless the stand § 174 is used) to make its working parts movable around a fixed centre which carries the needle, as this permits of exact adjustment in the true magnetic N. and S. line; such an instrument is shown Fig. 48. A brass rod or strong tube is fitted with three branching feet, each having a screw at its extremity for levelling; over this slides a brass tube, tight enough to be steady, but able to move freely, and provided with a collar and set screw to hold it when adjusted; on this tube the instrument itself is framed.

FIG. 48.



First there is fixed to it at right angles a table of wood or brass, a little lower and proportionately shorter than the diameter of the intended ring. The shape of this is of no great moment, so that it is large enough in the middle to carry the graduated card and cover, but it will be steadier if it tapers away from this to the ring. The ring may consist of a single band or rod of copper for powerful currents, or a flat band or stout wire may make several turns. The best plan is to make several circuits continuing in finer wires, with branches led out so as to give 1, 10, 100 times the influence on the needle; in this case the single turn must be in the middle of the wires to ensure perfect accuracy. For instance, upon a pasteboard ring wind forty-five turns of No. 20 wire, continue with four of No. 16, then a single turn of copper plate; next five turns of 16 and forty-five of 20. These must be so connected that the current enters at the one turn of plate, and continues, always in the same direction, through the nine turns of 16, making ten, and then through the ninety of No. 20, making one hundred; from each a wire is led to a commutator, which in the figure would be upon the lower table of the instrument, and constructed similarly to that shown Fig. 49, § 179. The leading wires of the single turn must be carefully arranged to secure their representing a true circle, neither more nor less.

From the middle of the fixed central tube rises the point on which the needle is to be placed just in the centre of the ring. The needle itself should be 1 inch long, but provided with a very light wire or sheet metal indicator, which will lengthen it to 3 inches. For this purpose the best thing to use is aluminum, because it is the lightest metal, and is very stiff, and may be obtained in sheets of extreme thinness and rigidity. Such indicators, if made of sheet metal, should be slightly curved lengthwise and also across so as to be slightly hollow, this gives great rigidity to the lightest metal. Of course greater sensitiveness is obtained by suspending the needle by a fibre from the top of the ring through a hole in the middle of the glass cover; a mirror may also be used, placed in this case in the same direction as the needle; the indicator also may be placed at right angles so as to be more easily read, and this has an advantage when the fibre suspension is used, as it gives four points by which the centrality of the needle is secured, and this is of course essential to accuracy; the eye must look along the indicator when reading the deflection.

176. VALUING THE DEFLECTIONS.—Any two or more deflections produced on the *same instrument* will have their relative values known by the law of the instrument, as they are related in the ratio of the tangents of the angles of deflection, but this does not enable the reading of *different* instruments to be compared. This requires the actual definite value to be known in some unit. This can be effected easily by means of the "chemic" unit of current: set up the instrument very carefully in circuit with a large-sized Daniell's cell with plates which can be weighed, or else with a coppering cell in addition; as even a Daniell varies somewhat, a variable resistance is also desirable, so that an exact uniform deflection can be kept up for an exact measured time. Let the experiment continue for ten hours or else correct the weight of copper deposited to that period, and divide this weight by 31·75

grains, the equivalent of copper; the resulting figure is the value of the observed deflection in "chemics." From this is calculated the deflection corresponding to one chemic, and then by the law of the tangents a table can be drawn up of the value of each degree, or of the degrees corresponding to each chemic; or, better still, a dial can be graduated to read off chemics direct. This is effected by fixing the dial upon a long table or board and drawing a line at right angles to the zero line as long as possible. From the centre of the dial, through the exact angle representing one chemic, a point is marked on the tangent line; this line is now divided into equal spaces (and subdivisions if required), corresponding to the distance of this, the one chemic point, from the zero line of the dial; lines from the centre to these various points upon the tangent line will mark upon the circle the points of deflection representing the values in chemics on the tangent line, as the needle when on these deflections is really pointing to the marks on the temporary line of tangents.

In like manner the tangent galvanometer may be graduated to indicate resistances when a given battery is in circuit, or the electromotive force when there is a fixed resistance; but while I explain this process for the benefit of readers, it is necessary to remark that no one is at liberty to make for sale galvanometers whose dials are thus graduated to indicate the values of the current and resistances in definite units, in place of mere degrees of arc, as this construction is patented. Instruments made upon much simpler plans than the tangent galvanometer when once thus graduated, as described § 180, entirely replace the tangent and sine galvanometers.

If preferred, the valuation may be made in vebers instead of chemics, as the Veber current represents 5·68 chemics. The Veber current being based on the absolute system, § 199, may be ascertained mathematically upon a tangent galvanometer, because it depends on the length of current acting, distance from needle, and the action of the earth and current on the magnet. Calling the horizontal intensity of the earth 1·764, r the radius of the coil, d its diameter, L the length of wire in the coil (all, of course, in metres), n the number of turns, and C the current strength, then in absolute units the current producing any deflection θ is

$$C = 1{\cdot}764 \frac{r^2}{L} \text{ tang. } \theta^\circ.$$

or

$$C = 0{\cdot}5615 \frac{d}{n} \text{ tang. } \theta^\circ.$$

Owing to the great increase in the value of deflections, the readings are not very reliable over 50°, as even a hair's breadth error in reading tells; thus at 50° a single degree is equivalent to three times as much as at 10°, to four times at 60°, ten times at 70°, and forty times at 80°.

177. THE SINE GALVANOMETER.—When a magnetic needle is removed from its normal position, the earth's magnetism exerts a force tending to replace it, proportional to the sine of the angle of deflection. The deflecting force of a galvanic current is at its greatest when the current is parallel to the needle; hence if the current is made movable, so as to follow the needle till it can deflect it no further, these two forces balance each other, and it is therefore evident that the force of the current is proportional to the sine of the angle the needle then makes with the magnetic meridian. The action of galvanometers based on this principle is more uniform than that of the tangent instrument, because while the sine of one degree is the same as the tangent, that of 90° is 1, the same as the tangent of 45°, and the sines gradually diminish in proportionate length, instead of, as in the case of the tangents, increasing so rapidly as soon to become almost useless as measures of action. But, on the other hand, their action is very limited, as the force should deflect below 90°. A sine galvanometer, therefore, to be of any extended use, should be made with connections enabling successive turns or layers of wire to be brought into circuit.

The construction is similar to that of the stand described § 174, the coils of wire being fixed to the upper movable disc; the needle usually works upon a point in the middle of the coils, and an indicator fixed to it at right angles stands over a zero line, from which it is not allowed to move more than two or three degrees, its play being limited by studs. In this case, therefore, there is an advantage in using a long and powerful needle, as the objections to this, § 171, do not exist here. On one of the discs is a circle of degrees, and on the other a pointer or vernier.

To use the instrument, it is set in the magnetic meridian with its indicator at zero and the pointer of the outer circle at 0°. On the current passing it presses the indicator against one of the studs, and the disc is then turned in that direction till the indicator leaves the stud and places itself on the zero line. The sine of the number of degrees pointed to on the outer circle is the relative value of the current, which may be converted into definite units in the same way as described, § 176, for the tangent galvanometer.

Any form of coil, and single or double needles may be used for sine galvanometers, and as remarked § 174, any galvanometer is converted into a sine one by standing it on the revolving table there described. If the current is too powerful for the instrument, it will carry the needle all round the circle. In this case shunts, § 272, may be used to send only a known part of the current into the instrument.

178. **Ordinary Galvanometers.**—These are of simple construction, but give no definite information unless their deflections have been valued or their dials graduated, by being included in the circuit of a tangent or sine instrument, the deflections of which are governed by varying resistances. It may be here remarked, also, that it is desirable for convenience' sake to note upon the face of a galvanometer the side to which a current deflects the needle, or, if several instruments are possessed, it is still better so to arrange the connections that all deflect the same way; for instance, if the screws are on the sides of the zero line, make the north pole always turn to the side connected to the positive pole of the battery. The simplest possible form consists of a mere rectangle of stout wire encircling the needle. The lower branch should be let into the wood frame, or even be on the lower side, so as to allow the graduated arc to be on the wood, and the needle should either curve down or be provided with a wire prolongation to come close to the graduation. For smaller currents, many turns of wire may be used without hiding the needle, or it may be fitted with an indicator, and the graduation commence at right angles with the needle. The value of the deflections of this, and of all the similar forms in which the coils surround the needle, is something approximating to the ratio of the tangents, but it is not uniformly so throughout, nor can any law be framed as governing them.

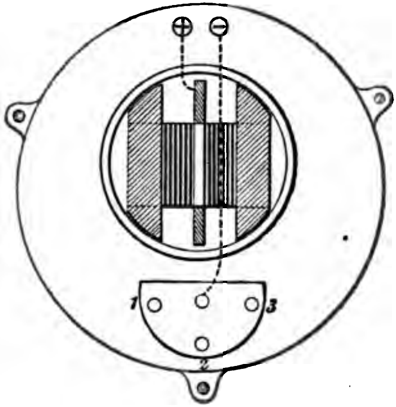
179. **Universal Galvanometers.**—Many amateurs wish to possess instruments fitted to the measurement of both weak and strong currents, but are deterred partly by the expense, but also by the inconvenience attending numerous instruments in limited accommodation, and both drawbacks are felt even by those who are prepared to make their own instruments, a course to be strongly recommended to all who wish to attain sound knowledge.

Instruments containing two or more circuits are not uncommon, but they are made upon no fixed principles. I devised the instrument now to be described to suit these requirements, and it led up to the one described in next section.

Fig. 49 represents a stand with three levelling screws; on it are fixed the coils of the galvanometer and a commutator for throwing different lengths of wire into circuit. The coils may be made in one frame on a flat copper tube, or as is usually done, in two parts, one on each side of the needle; the sides of the frames are secured to the stand either by brackets, or if made of wood, by brass screws passing up through the stand.

Even if made separate, the two sides of the coils should be mounted together on one mandrel for winding, so as to distribute the wires equally between the two. The chamber within the coils

Fig. 49.



in which the magnet plays, should be 2 in. long and ¼ in. deep, and the frame made 3½ in. long and 1¾ in. high, so as to form channels or spaces in which the wire will lie, ¾ in. wide and the same in depth all round the central chamber.

The laying on of the wire must begin in the middle, and each end must be connected so as to complete an exact turn at the middle, otherwise the indications will be inaccurate. First lay on 90 turns of No. 20 cotton covered copper wire, leaving 6 in. of the end for connection; the sizes given will allow exactly 10 turns to be placed in each channel, and thus four layers on each side will complete the 80 turns. Solder the end of the No. 20 (at the exact turn) to a doubled length of No. 18, leaving 4 in. or 5 in. to come out for the connection, and lay on nine turns of one of these wires in each channel, so as to divide the current between them. Finish with a strip of copper ¾ in. wide joined to the 18 wire, at the exact spot completing a turn, and leaving the end of the wire standing out; make one turn of the strip and bring its end, or a wire soldered to it, out for the commencement of the coils. This will give three circuits with decimal ratios (nearly) to each other. The wire ends are to be carried through the stand, and led to the required points. The two outside ends are taken as one (dividing the current) to the binding screw +; the next pair, representing one turn round the needle, are taken to 1 of the commutator; the next pair (joined, as close to the coils as can be, to the end of the

No. 20 wire completing 10 turns) are taken to 2; the first end of No. 20 wire which completes 100 turns goes to 3.

The commutator is similar to the one used frequently on medical coils, a central pillar connected to binding screw – and a spring from it traversing over the numbered studs. For some reasons it is better to use mercury cups thus; a block of hard wood an inch thick has central and radial holes ¾ in. deep by ¼ in. bored in it, and when fixed on a stand, holes are bored through just large enough to pass a No. 12 copper wire, on which a head has been hammered up. These heads are well amalgamated, and a piece of wire bent twice at right angles passes from the central cup to the one desired to be used; the resistances are thus kept very small, so that when used for measuring batteries, &c., they may be ignored in many cases.

All the connecting wires should be kept as close as possible to the middle line, so as to have little effect of their own upon the needle and neutralize each other.

The needle is 1⅞ in. long, of four strips of watch spring, and may be fitted with an indicator and mounted in either of the ways described, so as to play within the central space; if mounted on a point a long needle may be fixed in a piece of brass and screwed up through a hole in the stand and in the middle of the coils, with its point somewhat above the level of the frame. On the frame is secured a dial of cardboard, with an opening in the middle to pass the needle through, and a glass cover should go over all.

The graduation can be effected as before described, but the following values will approximate to the readings, if made exactly as described:

Chemics.	Degrees.
1	11·3
2	22
3	31
4	38
5	43
6	47·5
7	52
8	55·5
9	58
10	60
15	69
20	73
30	79
50	83·5
100	86·5

These figures represent the indications on No. 1 circuit: when No. 2 is employed they are to be divided by 10, and by 100 for No. 3. By using finer wires more circuits may be used, but the size of the frame must not be increased, and the whole space must be filled or the ratios will not hold good.

180. SPRAGUE'S PATENT UNIVERSAL GALVANOMETER.—While using the last-described instrument and discovering the defects in it as well as its utility, I worked out a principle by which an exact

multiplying ratio could be given to any number of circuits, and the disturbing effects of the various connections eliminated. I saw also that the plan I had long used personally of measuring currents direct, as described (but which no one else appears ever to have thought of as applicable to galvanometers), might be extended so as to make them read off resistances in ohms without the use of the expensive resistance coils. From these ideas has been developed an instrument which will soon be accessible to the public, and will, by simplifying the processes of measurement and placing them fairly in view, tend to spread generally those definite ideas of the measurement of electricity which make it a science instead of a mere hotch-potch of isolated facts, but which are at present confined almost entirely to professional electricians.

It resembles in some respects the instrument last described, but so modified as to ensure accuracy. It shows the current in vebers and in chemics as well as in degrees. It can be made to show any special work, such as the rate of deposition in pounds or in ounces per day or hour of any metal, or to measure other work done. When used with a Daniell cell (or several, as required) the indicator will point to the resistance of the circuit in ohms, and when used with a fixed resistance it will in like manner show at once the electromotive force of any battery used with it. It will thus do for many purposes, without other instruments and without calculations, the work which at present requires the Wheatstone's bridge and expensive resistance coils, as well as many calculations.

181. VERTICAL GALVANOMETERS. — For many purposes it is common to arrange the needle in a vertical plane mounted on a central pivot, in which case the needle is double, one working inside a coil, the other with its poles reversed working outside. Such an instrument—which is, in fact, the needle telegraph instrument—has its uses, but its indications cannot be relied on; they vary with the varying magnetism of the needles, because the resistance to motion is not the magnetism of the earth but the extra weight of the lower parts of the needles; the chief advantage is their instantaneous action, as the needle does not vibrate as in the horizontal form, and their ready visibility from a distance.

The sensitiveness may be increased if the axis of the needles is pointed at the back so as to work in a cup, by inclining the instrument, and so diminishing the height through which the weight has to be lifted for a given deflection. This form is frequently used in practical operations, such as testing telegraphic wires, from its portability and general handiness, and in such cases it is usually made with a double wire so as to be employed as a differential galvanometer. The construction is the same as that of horizontal instruments, the difference being in the mode of suspending the needles and the mounting in a case.

182. **Differential Galvanometers.**—These may be made in any form of construction. They consist of two exactly similar wires wound side by side throughout, but very carefully insulated from each other: they must have exactly the same influence upon the needle, and must also have exactly the same resistance. To secure the first, care must be taken that the wires are equally tightly laid, so that one has no greater length at any part than another. The wires should make a half twist at each layer, so that they shall be alternately the nearest to the needle; if this precaution is not taken, and a needle suspended by a fibre is used, the needle is apt to be drawn bodily towards one side, and to be deflected in opposite directions, according to the side it is drawn to, in which case no reliance can be placed upon it, as the least change of level will cause it to turn either way with the same currents. For this reason, probably, differential galvanometers are usually made with pivoted needles, thus lowering their sensitiveness. To test this equality of action the two coils are to be connected at the one end, so that the current goes by one and returns by the other; no deflection should be produced, however strong the current. If any effect is shown, it may be corrected by adding one or more turns of one wire, or if this gives over correction, then by unlaying a part of the wire having least influence and laying it again in its place somewhat loosely so as to lengthen it. The equality of resistance may then be tested by connecting up the instrument so as to divide a current between its two coils with reverse action, and adding wire at one of the connections outside the coils to the wire having most effect until they exactly balance, or the resistances may be equalized by means of the bridge, § 216.

A good differential galvanometer enables resistances as well as currents to be compared on principles similar to those explained § 214. If the two coils are exactly equal as directed, currents may be compared by passing them in opposite directions. Two resistances may be compared by putting one in each circuit, and then connecting to one battery so as to divide the current between them: if one is a resistance to be measured and the other a resistance instrument, by altering the latter till there is no effect upon the needle it measures the first resistance. Multiplying ratios are given to the instrument by means of shunts, § 272. These are provided to one or both the circuits in such way as to open other paths to the current and allow $\frac{1}{10}$ or $\frac{1}{100}$ of it only to pass the coils; then the actual resistance inserted in the other circuit has to be multiplied by 10 or 100 to give the resistance which it balances.

In using these instruments, when the resistance to be measured is equal to or greater than that of one of the wires, the resistance and rheostat should be inserted in the circuit as described; but if the resistance is less, it is better to couple the two circuits so as to neutralize each other, and to use the rheostat and resistance to be measured, as shunts, one for each circuit.

A differential galvanometer may be employed as a single circuit of alterable resistance and powers, as one circuit may be used alone, or the two coupled as one, reducing the resistance to half of that of a single circuit: or they may be used in series with double the resistance but double the action on the needle, each of which arrangements suits varied conditions of resistance in the rest of the circuit; such an instrument is therefore of use with the Wheatstone bridge.

183. **Thomson's Reflector.** — This valuable instrument is so purely technical in its uses, and scarcely employed except for delicate telegraphic purposes, that a full description is hardly required here, especially as it is rarely likely to be made by any one not familiar with it. It is usually constructed upon a vertical brass plate about $\frac{1}{4}$ inch thick, securely mounted by pillars upon an ebonite stand. In the plate and upon each side of it are turned circular recesses, leaving a thickness of less than $\frac{1}{8}$, the centre of which is also entirely cut away, as well as a vertical space in which hangs the needle system. Four reels, about $\frac{3}{4}$ inch wide and of 2 to $2\frac{1}{2}$ inches diameter, of brass or ebonite, with a central tube of $\frac{1}{2}$ inch bore, contain the wire, and are made to fit into the recesses of the plate and held there either by large headed screws or by turning small catches so as to grip the edge of the reels. The coils are connected in pairs, leaving four ends which are connected to binding screws, so that if the coils are exactly alike and carefully adjusted they may be used differentially, or at any rate be connected variously as described § 182. In some cases also there are double wires used to make the instrument a truly differential one. According to the purposes desired, different sized wires are used; but fine wire (No. 40) is generally used, and a resistance of 8000 or 10,000 ohms laid on.

The needle system consists of two pieces of watch spring $\frac{3}{8}$ inch long, cemented upon an aluminium wire so as to occupy the middle of the coil tubes: on the upper needle is also cemented a mirror made of a microscopic cover silvered and inclined so as to reflect a little upwards, and a slip of mica is fixed across the lower needle so as to act as a damping vane and also by touching the tube to limit the play of the needle. At the top of the supporting plate, and in a hole drilled exactly down the central line, is a sliding wire with a hole in its lower end to which is hooked a silk fibre attached to the aluminium rod of the needles: this fibre should have as much length as possible given it, and by slightly raising or lowering the rod the needles can be properly arranged for work, or lowered so as to take their weight off the fibre when moved about: this needle system should weigh altogether only 3 or 4 grains. The mirror is sometimes made somewhat concave, so as to concentrate the light at a given focus.

The instrument is covered with a cylinder of glass with a flat brass top, from the middle of which rises a brass rod fitted with a tangent screw to move it gently round. The rod carries a sliding tube on which is fixed a small magnet, by altering the position of which the needle is controlled, as to delicacy by the height of the magnet, and as to position by the line in which the magnet is placed, so as to supersede the small directive action of the earth upon the nearly astatic needle system.

The index is the beam of light reflected by the mirror from a lamp placed behind a screen 2 or more feet distant: usually a narrow slit is provided which thus sends back a narrow line of light: it is much better to use a $\frac{1}{2}$ inch circular opening with a vertical wire (which should be a dead black) stretched across it: this reflects a black line crossing the graduation, surrounded with light enough to enable the graduation to be observed. The light is improved also by being placed some distance back, with a reflector and concentrating lens adapted to the distance of the mirror, so as to get a bright spot which does not require so much darkening of the operating room. The deflections within the small limit of play allowed are proportional to the tangents of the angle of deflection, and, consequently, to a straight line divided into equal parts placed upon the line at right angles to that occupied by the coils.

The screen has upon it such a scale of equal parts mounted on a slide for adjustment, and the whole is to be so arranged that the indicating line or spot is upon the zero line, and is equally deflected to either side with reversed equal currents. A shunt is always provided with the instrument so as to send $\frac{1}{1000}$, $\frac{1}{100}$, $\frac{1}{10}$, or all the currents into the coils: by using these as accuracy of measurement is approached, observations can be made without throwing the needle about too violently. The instrument must be absolutely steady, and therefore fixed upon a brick pillar or upon a shelf fixed on a solid wall, otherwise the spot of light is always dancing about, and it is impossible to make any useful observations.

184. **German Silver Wire.**—For purposes requiring a high and constant resistance galvanometers are best made of German silver wire, owing to its small variation of resistance by temperature. But this only relates to external temperature: as relates to the heating effects of the current itself German silver wire is worse than copper, and therefore variations in the ratio of shunts

§ 272, will be greater with it than with copper. German silver increases its resistance only about $\frac{1}{9}$ as much as copper, but a wire of the same size would have 12 times the resistance, and therefore collect in it 12 times as much heat from the passing current. German silver wire is most useful in a galvanometer intended to measure electromotive forces by the process described § 270 (3), in which a high resistance is needed and one uniform in all experiments. Brass wire may also be used for the same purposes.

185. LIPPMAN'S CAPILLARY ELECTROMETER.—The 'Philosophical Magazine' for April, 1874, contains a very interesting paper which seems to open a new field of electrical research as well as new instruments for its study. It is well known that small tubes possess the power of elevating or depressing liquids in them by the force of surface adhesion between each liquid and each material of tube. M. Lippman has observed that the point of level in such tubes is altered when the liquids are polarized, that is, subjected to electric tension, and that the variation in the line of level is proportional to the degree of the electric tension.

A glass tube ·32 mm. in bore is connected by means of a flexible tube with a reservoir of mercury, provided with appliances for observing the heights of the surfaces: the upper part of the tubes enters a reservoir containing dilute sulphuric acid, which is connected to another reservoir of mercury, due care being taken to counterbalance all pressures except those which are intended to act. In these circumstances a difference of level of 14 mm. is produced by the capillary force of the tube. On forming the circuit of a Daniell cell through the two mercury reservoirs and the tube the level alters, the difference becoming 18·9 mm.

Upon these principles an electrometer or galvanometer (for it is both) is constructed, which it is stated is so sensitive that the effect of a feebly charged proof plane can be observed. Measurement is effected either by a graduation of the tube to be observed by means of a microscope, or by the height of the column of mercury required to bring the mercury back to its normal line.

By means of bundles of tubes connected to the two arms of a beam and by proper commutators, an engine is constructed which converts electric current into mechanical motion: if the action is reversed and the machine moved by external force an electric current is set up, and it is stated that these effects are produced more economically than by means of electro-magnets, as hitherto attempted.

186. MEASUREMENT BY CHEMICAL ACTION.—Faraday proved, see § 253, that whenever an electric current passes through a compound in a liquid condition (whether fused or in solution) the substance is broken up, its constituents separated into two parts, one of which

appears at the positive, the other at the negative pole, where they are either released, or by acting chemically on other substances, release some bodies equivalent to them. The laws of this action are studied Chapter IX., under the name of Electrolysis. This chemical action is proportional to what is called the "quantity" of electricity circulating; hence any such chemical action capable of ready measurement may be made the means of measuring the galvanic current which effects it. The process commonly used is the decomposition of dilute sulphuric acid; it is usually, but erroneously, termed the decomposition of water into its constituent gases, but really the acid alone is directly acted on, its hydrogen set free at one pole, while its radical SO_4, by some called oxysulphion, being incapable of separate existence, acts on a molecule of water, re-forms acid H_2SO_4, and sets free the oxygen; the practical result is, therefore, the same as though water were decomposed, and calculations may proceed on that basis.

187. VOLTAMETERS.—Instruments for this mode of measurement are thus named. Their form is subject to infinite variation, and every instrument maker devises his own variety. All that is essential are the two conductors, an outlet for the gases, and a means of measuring them, either separately or together. The great drawback to these instruments is the resistance they offer to the current, a large proportion of the force being absorbed by the mere work of measurement. This resistance is twofold. (1) Chemical. By the act of decomposition itself or even the tendency to it, nascent gases are produced in contact with the metallic surface, and the effect of this is to convert the instrument into a galvanic cell, the electromotive force of which is opposed to that of the battery. (2) Mechanical, dependent on construction. Most voltameters are made with small plates, and as this is equivalent to reducing the section of the liquid conductor, it causes great resistance. The plates should be as large as is convenient, and they should be platinized to facilitate escape of gas. Platinum is used because it is not acted on; graphite carbon would answer equally well, but for its tendency to absorb the gases.

A very simple form may be made from an ordinary wide-mouthed bottle. Two plates of platinum with wires attached are mounted on the cork with binding screws outside; in the middle of the cork a glass tube is fitted to carry off the gas by means of a flexible tube to an ordinary gas measuring jar: the end of this tube should project a little within from the surface of the cork and be cut off slanting so as to resist the ingress of moisture, and the cork should be boiled in melted paraffin.

If it is desired to collect the two gases separately, the cork should be fitted with two glass tubes as large as it will admit and going nearly to the bottom of the bottle. The tubes should be left open at the bottom, and closed at the top with a cork fitted as before with a gas leading tube and a strip of platinum: these giving off each its proper gas within the tube, completing the liquid circuit by the open ends dipping in the liquid.

For experiments with very small currents, as, for instance, those of induction coils, large surface is objectionable, as so much of the gas is retained by them and in the liquid: for such occasions a wire enclosed in a glass tube melted to it and exposing only the end, is used. These conductors may be fixed in small tubes and used as just described, or both may be passed through a cork in the neck of a small bottle with its bottom cut off, so that it can be used as a receiver in which two small test tubes can be inverted over the conductors, so as to make a model of one of the common forms of voltameter.

188. As before stated, these instruments are objectionable on account of their great resistance. It is, however, quite possible to have a voltameter which not only shall not give any resistance, but shall help the current. A Smee cell is to all intents a voltameter, if we collect the gas given off, and ascertain how much of it is due to local action; the mode of effecting this is described § 124: a cell for this purpose should be large enough not to lower the current by its resistance, and its outlet should be closed when not in use, so as to keep the liquid charged with gas.

189. We have now to learn what the measure of gas given off teaches; a point which electrical writers usually fail to clear up, because they take the actual measure itself as the primary matter, instead of treating it as an incidental effect, and thus base upon it all sorts of arbitrary units, as, for instance, Jacobi's unit of current, that which in one minute generates one cubic centimetre of mixed gases at 0° C. and 760 mm. barometer. The thing really wanted is to know what *measure* of gas corresponds to such a definite system in weights as furnishes the unit or "chemic" current, to value the indications of the voltameter as in § 176 those of galvanometers are valued. We require, in fact, to know what *measure* corresponds to those *weights*, not to set up a different set of ideas altogether. By the system of weights the current is measured by the number of equivalents of any substance acted on, ascertained by dividing the total weight by the known equivalent weight. Now the system of measure is still more simple, for every atom of a simple substance, or still more inclusive, every molecule of any substance, simple or compound (with a few exceptions), occupies in the gaseous state the same volume, no matter what its weight is. What we want is the relation between the equivalent and this molecular volume.

In water, H_2O, there are three atoms, all of equal volume; but as to weight, hydrogen being unity counts 2, and oxygen by its atomic weight 16, makes the molecule of water 18, which answers to two electric equivalents. Once we know then the measure or bulk of 1 grain of hydrogen, we know the weight of the same bulk of every other gas, the constitution of which we know.

The best mode of measuring gases is by the metric system reckoned at 0° C. temperature (freezing) and 760 mm. barometer (one atmosphere) correcting to actual temperature and pressure; but as exact accuracy is never attainable in this particular case, because part of the gases is absorbed, it is near enough to take the average condition at 60° Fahr. and 30 in. bar., at which, according to Miller, 1 grain of hydrogen occupies 46·73 cubic inches, which may be considered the unit or atomic volume.

Therefore, for each unit of quantity or current there will be given off—

In the modified Smee voltameter, 46·73 cubic inches of hydrogen.

In the double voltameter, the same in one tube, and 23·36 cubic inches of oxygen in the other.

In the single-tube voltameter, 70·1 cubic inches of mixed gases.

A tube of glass, such as the ordinary Mohr's alkalimeter, can easily be graduated to measure this off direct: 46·73 C. I. = 11797·45 fluid grains, therefore a tube containing 1179·8 grains divided decimally would contain one-tenth of a unit, and require one hour to fill by a chemic current from a Smee voltameter.

190. As any one of the reactions which take place in a galvanic circuit will answer for the purpose, the best voltameter for many purposes is two plates of copper in a coppering solution. If a Daniell with flat plates is used this system also will supply instead of absorbing energy. The weight of copper divided by 31·75 as explained § 176 will give the required information.

191. **Measurement by Heating Effects.**—Whenever current passes through a wire it meets a certain fixed resistance, in overcoming which the equivalent proportion of energy is converted into heat, and the current, therefore, is capable of measurement by this heat. As an illustration of the erroneous notion of the older ideas, such as that heat is the two supposed electricities united, it must be understood that this conversion into heat of the force of a galvanic current does not in the least reduce the "quantity" of the electricity; that is to say, a current arising from the consumption of one unit of zinc will deposit exactly the same quantity of copper, viz. one unit, whether it passes directly to the coppering cell, or whether a long fine wire, in which heat is developed, is also

interposed in the circuit; the only difference will be that it will take much longer about it. This is explained by the general principles of the circuit, § 274.

Experiment, has, however, settled that—(1) In a wire of given resistance (ignoring the variation produced by the heat itself in the wire), equal currents always generate the same amount of heat. (2) With different currents the amount of heat varies not in the ratio of the currents themselves, but in the ratio of the squares of the currents; thus, if a current of one unit produces in a given wire one heat unit, that is, sufficient to raise one pound of water one degree in temperature in a minute—then a current of two units will produce in the wire four such units of heat.

This is expressed mathematically $H = C^2Rt$; to give the heat developed in a given time any fixed value, a constant which is the heat equivalent of the current in a unit resistance for a unit time (such as one second) must be employed with the formula; for which see § 257.

192. **Calorimeters.**—These little-used instruments are thermometers containing a platinum wire, through which the current passes. There are two kinds: (1) an air thermometer—a bulb with a fine graduated stem containing liquid; the platinum wire crosses the bulb: (2) a vessel containing a known weight of a non-conducting liquid, such as water or alcohol; the wire passes through this and a thermometer shows the temperature generated, which, with the specific heat of the liquid, gives the actual heat. Thus, if a pound of water is used, each degree represents a unit of heat, and if the resistance of the wire is 1 ohm the calculations are very simple, see § 275.

193. **Heating Effect upon Wires.**—The formula in § 191 expresses the actual heat as quantity of energy; but another consideration of moment is the temperature to which that quantity of heat can raise a particular wire. This depends upon several considerations, such as the weight of metal in the wire, and the specific relation of the metal itself to heat (see §§ 13, 108, and 196), i. e. its specific heat. A general formula may be given for this, not reckoning, however, the heat lost by radiation and conduction.

$C.$ = Current in vebers.
$R.$ = Resistance of wire in ohms.
$W.$ = Weight of wire in grammes.
$s.$ = Specific heat of metal.
$H.$ = Rise of temperature per second in degrees Centigrade.
$\cdot 24065$ = Calories equivalent to veber.

$$\text{Then } H = \frac{\cdot 24065 \times C^2 \times R}{W \times s}.$$

In this and similar formulæ the metric weights are necessary, because the units are themselves based upon them. The specific heat of metals increases as they approach the temperature of fusion; and, therefore, platinum varies less than other metals. The following figures are the average between 0° and 300° C.

	Specific heat.	Melting point.
Copper	·1013	1091
Iron	·1218	1805
Silver	·0611	1023
Nickel	·1155	1800
Platinum	·0355	2100
Zinc	·1015	412

The specific heat of alloys is the mean of that of their components, and is ascertained by multiplying each specific heat by the percentage of the metal and dividing the sum of the whole by 100. This only holds good at a distance from the melting points, which are usually not the mean of the constituents, but lower; and it is doubtful if it applies to those alloys which, like German silver, differ in resistance greatly from that of the means.

The effects may be compared upon the system of English weights and units used in these pages, by taking as the heat equivalent the grain instead of the pound of water. Then the worth of the Veber current is 6·6855 such grain degrees Fahr., and that of the chemic $(5{\cdot}68)^2 = {\cdot}20722$.

The length in feet of a wire weighing 1 grain per foot, which gives 1 ohm resistance, is of course the weight in grains, and is for copper 4·845 and for platinum ·2828, and as in these different lengths or weights equal actual heat is produced, it is evident that very different heating effects must be exhibited; but the specific heat has also to be considered, and this, again, greatly increases the difference.

If we multiply the unit heat of current (above) by the reciprocal of the specific heat (that is 1 ÷ specific heat), we get the number of grains of the metal that unit heat would raise 1° Fahr., and dividing this by the length of the grain-foot ohm (the unit wire, § 226), we get the actual rise of temperature produced in that wire for a Veber current as 14·5° for copper and 730° for platinum; that is, a current which would only warm a copper wire slightly would raise a platinum wire to a red heat.

In an experiment with such a platinum wire, I obtained the curious result that the loss of heat and gain so balanced each other that the actual temperature maintained by the current closely corresponded with the calculated rise.

Heat of Wires.

Heat observed = to Degrees Fahr.		Current in Chemics.	Calculated Heat.
1. Veber current		5·68	730
2. Faint red	1000 1300	7·	1109
3. Cherry red	1400 1800	8·	1473
4. Orange	2000 2200	9·5	2042
5. White	2350 2700	10·7	2585
*6. Fused about	3700	12·6	2847

Of course, the coincidence noted was accidental, and only holds for the very fine wires.

In heating wires, it is to be remembered: 1. The same *current* will heat an inch or a mile of the same wire; the *length* heated in any given conditions is purely a question of resistance, and the force employed to pass the current. 2. To heat, equally, thicker wires, the *current* must be increased as the weight of wire per foot increases.

The arrangement of batteries to produce these two effects is number in series for the first, large cells for the second; and the resistances and electromotive forces must be arranged so as to produce the required current.

194. **Principles of Measurement.**—As soon as men passed that first step of civilization in which they bartered with each other from hand to hand articles presented to the sight, and required some more abstract idea of value and quantity, they naturally selected for their unit some common object; thus our early English weights appear to have been in some degree based on the barleycorn, while the many "stones" of our country districts were possibly at first actual stones used by some eminent individuals as weights, which afterwards became a sort of local standard. These weights, &c., naturally grew up to larger ones by the process of doubling, and hence was gradually generated the present system of weights and measures. The intolerable burden of the calculations these

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* The last line of the experiments illustrates the fact that the breaking of a wire by the galvanic current is not due to pure fusion, but occurs at a lower temperature. The effect is partly analogous to the destructive effects of lightning. The fusing point is, in fact, that point at which the vibratory molecular motion of heat, §§ 13 and 29, just overcomes the molecular attraction of cohesion; but, if electric transmission also involves a motion or revolution of the molecules, it is obvious that this effect must be added to that of heat and destroy the cohesion at a lower temperature.

inflict upon modern commerce must ultimately induce even "practical" England to get rid of them, as the more scientific and generalizing French mind has long ago.

Exactly the same process has been followed in scientific matters; in earlier times, before the whole aspect of science had burst upon the mind of man, the more salient phenomena of each division of natural knowledge were first observed; subsequent observations were referred to and compared with these, and thus grew up a set of merely "practical" systems of measurement based upon isolated facts, and even worse, expressed in the confusing system of common weights and measures. Hence, in electricity we have such measures of action as that referred to in § 189, and many similar ones, all based on isolated facts. As electricity assumed the state of an exact science, and was brought into subjection to mathematics, the evils of this system became so intolerable that an effort was made to remedy the nuisance, and an organized system of electrical measurement has been devised under the auspices of a committee of the British Association.

195. Most unhappily for science the gentlemen on whom this duty was devolved, being mostly trained mathematicians, failed to escape altogether from the trammels of the "practical," and the bondage of mere mathematics; and, in consequence, perfect in itself as is the result of their labours, they have certainly thrown back science many years in its progress and interposed a formidable barrier in its way, because the very perfection of their system keeps out of sight its fundamental error, viz., the perpetuating the old arbitrary system, instead of seeking a truly scientific starting point. This evil, which very few people even yet comprehend, is analogous to the errors of the old astronomy: it looked at the universe from the earth, and tried to bring all the observed motions into a system subordinate to the earth; hence inextricable confusion. As soon as man adopted nature's centre, and looked at the universe from the sun, all confusion disappeared, and perfect harmony and simplicity were at once presented to the observer. Exactly so with every other science. When we want to weigh and measure nature, her forces and works, we ought to take for our units *measures which nature herself uses.* Of all the sciences, however, chemistry alone does this, and in consequence has made the most rapid progress since this plan, otherwise known as the atomic theory, has been employed; for what is the atomic theory, but the substitution, for the incomprehensible and unmeaning relation of pounds weight or pint measures of matter, of the idea of *nature's unit, the atom of matter without reference to weight or size,* except when these are required for practical purposes, and then ascertaining the weight of each form of matter which nature has

put into her unit of each element? Even yet some chemists, unable to rise to the clear conceptions this theory gives, ungratefully endeavour to set it aside as a "mere theory," useful, but imaginary, forgetting that, quite independent of its chemical importance, all the physical sciences are rapidly coming within the scope of the atomic theory. They would do so completely and their progress be greatly increased, were it not for the trammels of the units employed, based on arbitrary weights and measures.

196. **Heat Units.**—Thus in heat we have many units, the usual English one being 1 lb. weight of water raised 1° in temperature; and to connect this with any special work, and so value it, we have to use whole rows of figures, each of which teaches only its own lesson. In mechanical force we have thus the foot-pound as our English unit. Now nature knows nothing about pounds or feet; and as we therefore interrogate her in an unknown tongue, she was unable to point out to us that between heat and mechanical work there is a definite relation, and though she puts that fact before us in a thousand ways, we cannot see it. Having, however, by the patient labour of many minds, at length discovered it, we do our best to disguise it by saying that the unit of heat is equal to 772 units of work. Now what sort of idea is conveyed to the mind by saying that raising the heat of 1 lb. of water 1° is equivalent to lifting that same pound of water 772 feet? Nor is the matter in the least improved by substituting the French metric system for the English, for this is none the less arbitrary, the only advantage lies in the decimal system simplifying calculations.

Yet all the while nature is calling on us to adopt her own system, to use her unit—the atom—for our unit. Thus, if we take several substances and heat them to the same point and measure the actual heat absorbed, we can discover no relation of cause and effect. We are using the wrong unit, as the following table makes very clear:

Substance.	Specific Heat	Atomic Weight.	Product or Atomic Heat.
Lithium	·94806	7·	6·59
Iron	·11380	56·	6·37
Gold	·03244	196·	6·36
Platinum	·03243	198·	6·42
Water	1·	$\frac{18}{3}$	6·

In the first row of figures we have the relative quantity of heat necessary to raise 1 lb. weight of those several substances 1°, at ordinary temperatures; that is to say, these puzzling figures are all our unit, the pound, can teach us. The next column gives us nature's unit, and by interpreting the first figures by this we get a uniform result, allowing for inevitable errors of observation and the energy absorbed in internal work, such as expansion, &c. But we still go on talking about specific heats; we still call the atomic heat 6·4, though nature is urging us to call the atomic heat 1, and make this our starting point, instead of the absurd, because arbitrary, pound of water. Now if we go to gases we have yet further teaching.

Name.	Specific Heat.	Molecular Weight.	Product.	Equal Volumes.
Water as steam ..	·4805	18·	8·65	·2984
Hydrogen	3·4090	2·	6·82	·2359
Oxygen..	·2175	32·	6·96	·2405
Chlorine	·1210	71·	8·59	·2962

Here we have in the first row similar incomprehensible figures, reduced to comparative uniformity by taking the molecular weights into account. Here we find the *molecular* heat of pure gases approaching the *atomic* heat of solids, while steam and chlorine, which are easily condensable, are intermediate, giving us plain hints as to how we may trace out the relations of force to physical state, and to the work done in expansion and altering molecular structure; hints which are mere unmeaning hieroglyphics as long as we persist in trying to deal with them by pounds instead of by atoms and molecules.

197. If we now expose an atom, that is, any unit of weight, be it a grain, a gramme, or a pound of hydrogen, or, what comes to the same thing, an equal volume of any other pure gas under the same conditions, to heat, we find it requires different amounts of heat to produce the same heating effect, according as we allow it to expand or confine it, i.e. according as we keep the volume or the pressure constant. Expansion means *lifting the weight of the atmosphere*, and whatever excess of pressure is put on the gas; hence the difference between the heats of constant volume and constant pressure is *nature's unit of work*. By it she tells us that with the same heat or energy she can either raise the temperature of one atom of elementary matter, or she can raise a given weight; but if we are to understand her lessons, we must make *this weight*, not the foot-pound, our unit, because then the unit of heat and work will be the same, and their relations will at once become self-evident. Had the metric system been based upon this principle, using a fixed volume of hydrogen at normal pressure as the unit of weight and measure, instead of water, the system would be as valuable scienti-

fically as it is now practically, for it would have been correlated to the atomic system of nature, and its relation of constant volume and pressure would have furnished a fundamental unit for all the natural relations of matter and energy.

Now to come to our special subject, this same unit of work and heat will furnish us with that of electrical force; for it must be remembered these units are abstract and relative, not concrete and absolute; we can translate their results into any system of weights, &c., by simple multiplication, just as a table of atomic weights is equally intelligible to an Englishman using grains or pounds as to the Frenchman using grammes.

Beautifully simple as the whole system of scientific measurement would become if this one natural unit were used as the base, it requires a great deal of work to be yet done before we can employ it, because so much work has been wastefully employed. We still need some very careful experiments to eliminate the various sources of error, and ascertain exactly what the true atomic unit is in any system of weights, and meantime it is necessary to employ and endeavour to comprehend the units at present in practical use.

The system devised by the committee of the British Association is the only one thoroughly worked out, and is now generally adopted in England in practice, though few people really understand it, and there is much confusion in the various explanations of it offered by different accepted authorities. The following is an endeavour to make it comprehensible to ordinary minds without much mathematical knowledge, and it relates principally to those parts of the system bearing upon current electricity.

198. It will be best first to explain the object of the system. The mathematical expression of the phenomena of electricity known as Ohm's law, is now universally accepted, and thoroughly satisfactory; it is entirely independent of any theory whatever as to the nature of electricity, but merely expresses the conditions of the observed facts; and to do this embodies them under certain heads. The fundamental expression is that *a force*, be it what it may, produces the observed effects; and this is called electromotive force, symbolized by E. Its necessary first consequence is a *tendency to action*, which is called tension, potential, &c. This is opposed by the various circumstances, molecular construction of the substances, insulation, &c., all of which are embodied in the general term "resistance," symbolized by R, which again simply expresses a fact, but no theory whatever. The result is action measured by the relation of these two, and called "quantity," Q; and when time is taken into consideration it becomes "current," or quantity in a given time, symbolized by C; this is very commonly called "intensity of current," and symbolized by I; this mongrel term, derived from the translators of the French phrase "intensité de

courant," strength or amount of current, leads to great confusion of ideas, because intensity has, in the earlier English books, a distinct meaning which corresponds to tension, and has no connection with current or quantity. The object of the B. A. system is to furnish a defined unit for each of these mathematical expressions, so that all the actions of electricity may be capable of exact definition and comparison with mechanical work. This object it would be impossible to carry out with the confused English measures; therefore the systematic French metric measures have been employed, and in these alone is it possible to explain the system, though an endeavour is made, § 257, to convert its chief units, &c., into familiar English measures.

199. THE ABSOLUTE UNIT.—The effect of a constantly acting force upon a body capable of motion is to move it with an increasing velocity, and the strength of a force is measured by the "velocity" it has imparted in a given time, this *velocity* being in fact double the actual space moved through; thus the attraction of gravitation in England causes a body to fall at the rate of 16·1 feet in a second, and therefore the velocity due to gravity in one second is 9·811 metres (English 32·2 feet). But gravity is a force which varies with locality, because of the form of the earth. The theoretical unit of force must be unalterable and be expressed by single figures; this is the absolute unit, and any actual figures might be employed, but those selected are weight, 1 gramme; length or space, 1 metre; time, 1 second, and the fundamental "absolute unit" is a force which acting for one second would give a weight of 1 gramme, a velocity of 1 metre per second. Some use the centimetre for small forces, but this is only a source of confusion, and in these pages nothing will be referred to but the metre gramme second as the absolute unit. From this are derived all the other units as shown in the following formulæ from the Reports of the British Association Committee, and given in Messrs. Clark and Sabine's work.

200. FORMULÆ OF THE ABSOLUTE UNITS.

1. Fundamental units.

L	Length or space	= 1 metre.
T	Time	= 1 second.
M	Mass	= 1 gramme.

2. Derived mechanical units.

$$\text{Work,}\quad W = \frac{L^2M}{T^2}.$$

$$\text{Force,}\quad F = \frac{LM}{T^2}.$$

$$\text{Velocity,}\quad V = \frac{L}{T}.$$

3. Derived magnetic units.

Strength of a magnet pole .. $m = L^{\frac{3}{2}}\ T^{-1}\ M^{\frac{1}{2}}$.
Moment of a magnet .. .. $m\,l = L^{\frac{5}{2}}\ T^{-1}\ M^{\frac{1}{2}}$.
Intensity of a magnetic field .. $H = L^{-\frac{1}{2}}\ T^{-1}\ M^{\frac{1}{2}}$.

4. Electromagnetic system of units.

Quantity of electricity .. .. $Q = L^{\frac{1}{2}} \times M^{\frac{1}{2}}$.
Strength of a current .. .. $C = L^{\frac{1}{2}}\ T^{-1}\ M^{\frac{1}{2}}$.
Electromotive force .. .. .. $E = L^{\frac{3}{2}}\ T^{-2}\ M^{\frac{1}{2}}$.
Resistance of conductor .. .. $R = L\ T^{-1}$.

5. Electrostatic system of units.

Quantity of electricity .. $q = L^{\frac{3}{2}}\ T^{-1}\ M^{\frac{1}{2}} = v\,Q$.
Strength of current .. .. $c = L^{\frac{3}{2}}\ T^{-2}\ M^{\frac{1}{2}} = v\,C$.
Electromotive force .. .. $e = L^{\frac{1}{2}}\ T^{-1}\ M^{\frac{1}{2}} = \frac{E}{v}$.
Resistance of conductor .. $r = L^{-1}\ T = \frac{R}{v^2}$

v = 310,740,000 metres per second, the ratio of the electrostatic to the electromagnetic unit of quantity.

201. Values of the Units.—From the foregoing it results that the absolute unit is a single expression for all the forms of energy, while the practical units in ordinary use have a known value, and may be converted into absolute units.

A unit magnetic pole is one which repels a similar one weighing 1 gramme at a metre distant with one unit of force.

A unit *quantity* of electricity is that which repels an equal opposite charge a metre distant with a unit of force.

A unit *current* is one which, in a wire 1 metre long forming an arc of a circle of 1 metre radius, repels a unit pole at its centre with one unit of force—that is, arranged as a tangent galvanometer a wire forming a circle of two metres diameter would exert 6·2832 units of force on such a pole. The unit current in a straight wire of 1 metre long, repels a similar one 1 metre distant with one unit of force.

When a magnet is moved into a circle of wire or the reverse, a current is generated in the wire, and the earth being a magnet the same effect is produced by it, and though we cannot do this really with the earth, yet the result is the same if we revolve a ring or coil of wire across the lines of magnetic force, only we get reverse currents at each half revolution, which, by means of commutators, can be converted into a continuous current in one direction; the axis of motion may be horizontal or vertical, but its true position is at right angles to that of a dipping needle; if placed in the magnetic line no current is generated.

Let us now take a ring of 1 metre radius thus arranged vertically; as it revolves, the current reversing when the ring is at right angles to the magnetic meridian, and at the same time the ring altering its relation to a needle at its centre, the action on this is uniform; the current developed will depend on the number of magnetic lines traversed, and therefore on the speed of revolution. As this increases, the needle will deflect more and more, and when this deflection reaches 45°, the current is equal in action to the magnetic influence of the earth, and this being known, the various relations may be calculated; for, to quote an authoritative definition, "the unit of electromagnetic force is the force of a current, which, when it traverses a circular conductor, whose sectional area is equal to the unit of surface, and acts upon a magnet whose magnetic moment is equal to unity, the magnet being placed at a great distance, and in such a manner that its axis is parallel to the plane of the conductor, and its centre in a line drawn through the centre of the circular conductor, and perpendicular to its plane, exerts upon the magnet a rotatory force equal to unity divided by the cube of the distance between the centre of the needle and the centre of the conductor."

The force of the current generated in this apparatus is evidently equal to two distinct things. 1st. The effort or work expended in producing the current, which generates an equal resistance to motion—that is, if we ascertain the amount of work necessary to produce rotation with the axis in the magnetic line, when no electric current is produced, and that required to produce the same rotation when the current *is* produced, the difference is the mechanical equivalent of the current. 2nd. The current, or, rather, the electromotive force producing it, is equivalent to the resistance of the wire in which it is produced, multiplied by the revolutions, and this may be expressed in terms of *velocity*—that is, in the metre second, the unit of force, making force and resistance equivalent. I cannot put this in better terms than those of Dr. Ferguson, in his philosophically written little work; referring to the ring described, he says, "to reduce the motion of the ring to the equivalent motion" of the unit metre length, "we must project the motion on a vertical plane at right angles to the magnetic meridian. The semi-revolution of the sphere described by the ring projected in this plane is the area included by the ring—namely, 3·1416 square metres, and by a whole revolution twice this, or 6·2832 square metres. If ten revolutions per second produce a deflection of 45°, the effective area is 62·832, which is equivalent to a metre slider" (or unit metre length) "moving at the rate of 62·832 mètres per second. But we reckon the current from 1 metre of it, so that the velocity of the ring must be 6·2832 times increased to give 1 metre the effect of the whole circumference; the equivalent velocity of the metre slider must thus be 394·7. The resistance of the wire (of which the ring is made) is thus 394·7 metres per second, and we can easily calculate the length of it necessary to produce a resistance of 1 metre, or 10,000,000 metres, the B. A. unit." *

It was by an apparatus of this kind and by prolonged careful experiment that the actual values of electric resistance were established, and by this the other required information and units ascertained on principles which may be summed up in Fleeming Jenkin's words. "A battery or other rheomotor of unit electromotive force will generate a current of unit strength in a circuit of unit resistance, and in the unit of time will convey a unit quantity of electricity through this circuit, doing in the same time a unit of work or its equivalent. These relations leave the absolute magnitude of the series undetermined. Weber has proposed to fix the series in various ways, but the most convenient, where measurements have to be made by observations conducted by the aid of magnets, is probably that in which the series is fixed by the definition of the unit current, as that current the unit length of which at a unit distance exerts a unit force on the unit magnetic pole. The definition of the unit magnetic pole by Gauss and Weber, in its turn, depends solely on the units of mass, time, and length."

202. PRACTICAL ELECTRIC UNITS.—The absolute unit is an infinitesimal thing having no existence, a simple agent for calculations; in practice actual units of suitable magnitude are necessary, and the connection of the units permits only two to be selected, the rest follow from these by the laws of the system. Those selected were for electromotive force, one nearly approximating the Daniell cell, as a practical unit, yet a decimal multiple of the absolute unit; the other, for resistance, being a near approximation to an already well-known unit, Siemens' mercury tube. Names were given to the several units from those of distinguished electricians. Thus were arranged the following:

Electromotive Force and Tension	the Volt.	100,000
Static Quantity	the Farad.	·01
Resistance	the Ohm.	100,000
Quantity or Current	the Veber	·01

203. ELECTROMOTIVE FORCE.—Force or energy is the generic term for the sources of all the actions we are acquainted with, and modern science regards it as *motion* in some form when active, as

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* Resistance may also be regarded as a mechanical resistance, and measured as the energy required to overcome it. On this view 1 ohm is the equivalent of 4673 foot-pounds, § 257, under unit conditions.

the tendency to motion when in the latent or *potential* condition. We call it

Work, as relating to masses of matter.

Affinity, in the chemical relations of atoms of matter.

Cohesion, in the relations of molecules of the same body.

Adhesion or friction, as related to the superficial molecules of different bodies.

Heat, as related to the atoms and molecules of matter each moving independently among its neighbours.

Electricity, when connected with a complete circle of polarized molecules, this being the essential condition of electrical action.

Electromotive force, then, is any action or power which tends to produce this polarized connected circle of molecules, and its degree is measured by the amount of tension or strain it can produce on such a circle.

Friction develops electromotive force through the adhesion between superficial molecules in contact.

Chemical affinity by its efforts to break up the molecules acting on each other.

Mechanical motion produces it by exertion against the action of molecules; but all produce it only if the required conditions are present, otherwise they produce heat, &c.

The Volt.—This unit is simply a measure of a static force, but there exists no standard of it, and it is therefore purely a matter of calculation, being the hypothetical force needed to fulfil the conditions laid down in § 201. It is 10^5 or 100,000 absolute units. Its nearest practical representation is the Daniell cell in perfect order; the force of this cell is, according to the best authorities, 1·079, that is, the unit electromotive force is ·9268 of a Daniell cell. As the force exerted in a thermo-electric battery is constant for given ranges of temperature, the standard volt might be obtained by ascertaining the number of the alternations of two metals, copper and iron for instance, the junctions of which alternately at the freezing and boiling points of water furnished the exact force; but as the Daniell cell is a convenient and practical electromotor, always at hand and easy to experiment with, it is probably the most convenient, subject only to correction by the above figures. Table XVIII., § 264, of the forces of the various other batteries in common use will enable calculations to be made of the forces of any combination.

204. TENSION.—This is very commonly regarded as the same thing as electromotive force, but really it is its first action; although the two are always equal they are differently localized; the force lies only at the point of original action, the tension is distributed over the whole circuit. This is explained § 215.

Tension is analogous to pressure, and is a purely static condition. Hence tension never manifests itself *per se*; all the effects of what is called static electricity are effects of leakage, or they result from some action which alters the resistance of the circuit and which therefore also alters the tension. The reason of the enormous tension of frictional or static electricity is that it is developed against high resistance, the circuit being almost entirely composed of dielectrics or non-conductors, substances of high specific resistance.

The volt is the unit of tension also.

205. POTENTIAL.—This word is growing into so much use in electrical writings that it is perhaps desirable to explain why it is not used in these pages. That reason is that at present it has really no definite and accepted meaning. Two quotations from leading electrical writers will show that this is the case.

Latimer Clark, in his 'Electrical Measurement,' p. 10, says, "We will now treat of electric *tension* or *potential*. The two terms *are perfectly synonymous*, but the word potential is generally preferred by mathematical writers." Fleeming Jenkin, 'Electricity and Magnetism,' p. 26, says, "The word potential, introduced by Green, has only lately been generally adopted by electricians, and is still often misunderstood; it expresses a very simple idea, and one *quite distinct from the meaning of any other term* relating to electricity."

In fact, the word is almost always used in place of tension or electromotive force, because there is something full and smooth sounding about it; but the idea which really does belong to it is a pure mathematical abstraction which only highly trained minds can apprehend. What that abstraction is may perhaps be seen from Jenkin's definition of the "simple idea." "Difference of potentials is a difference of electrical condition, in virtue of which work is done by positive electricity in moving from the point at a higher potential to that at a lower potential, and it is measured by the amount of work done by the unit quantity of positive electricity when thus transferred." "The potential of a body or point is used to denote the difference between the potential of the body or the point, and the potential of the earth."

Words whose meaning is indefinite are delusions, and as electromotive force and tension have definite meanings which the mind can grasp, those words are used here. The idea "potential" is really meant to convey, is one required only in the highest and most delicate branches of electrical science, and the word is best confined purely to its proper object.

206. QUANTITY.—THE FARAD.—There is a considerable amount of difference among authorities as to this unit, only, however, as to a difference of a million times; it will probably be ultimately

settled on the basis of the doctrine in § 201. Clark defines it as "that quantity of electricity which, with an electromotive force of one volt, would flow through a resistance of one megohm in one second." This is not in accordance with the principle, but really describes one-millionth of the true unit, or what Varley calls the microfarad.

Although the farad is thus described as flowing, it really is a static unit; it means the amount of charge a condenser is capable of, and its most common use is as a measurement of the static charge which each wave of electricity imparts to a cable before it makes itself manifest at the distant end.

It is therefore the unit of capacity, § 60, and as it belongs to the subject of cable telegraphy is best studied in technical works.

207. CURRENT.—THE VEBER.—This obviously should be the same thing as the unit of static quantity; it is furnished by the fundamental principles in accordance with Ohm's laws. Thus $C = \frac{E}{R}$ the current is proportionate to the electromotive force divided by the resistance; substituting units, therefore, this gives $\frac{1}{1} = 1$, or by the actual values in absolute units,

$$\frac{\text{Volt}}{\text{Ohm}} = \frac{100{,}000}{10{,}000{,}000} = \text{Veber } \cdot 01,$$

or one hundredth of an absolute unit; and therefore, by the laws of the current, the energy absorbed by a Veber current in an Ohm resistance is $(10^{-2})^2 \times 10^7 = 1000$ absolute units. Some works give the unit of current as one-hundredth of this, but this is a mistake. The chemical value of the Veber is shown in § 224.

208. RESISTANCE.—THE OHM.—Here we have something really definite, for it has a fixed value ascertained, and standard measures are issued. It is equal to ten million absolute units. Resistance is so important an item of electrical science that it requires full explanation. It is whatever opposes that act of polarization and discharge along a chain of molecules which constitutes the electric current, and every substance has its specific resistance; this means that each such substance requires a definite exertion of force to set up the state of polarization and effect discharge. When this resistance is very great, the substance is a non-conductor or dielectric, such as guttapercha. In metallic wires each also has its specific resistance for given lengths. These various actions are explained under the different heads; but let the actual cause or source of resistance be what it may, all may be expressed by any one, and the most convenient is the measure of length of a wire of known resistance. Hence arose a great variety of units based upon any standard

which was at hand, such as a length of copper or silver wire of a given size. Of these arbitrary units Siemens' is really the best, because based on mercury, a metal easily obtained pure; it is one metre in length of mercury in a glass tube one millimetre diameter at the freezing point of water. Varley's unit is a mile in length of No. 16 copper wire, but this is a very uncertain measure. Wheatstone used a copper wire, 1 foot of which weighed 100 grains. The standard B. A. units or ohms are made of an alloy of platinum and silver, which changes its resistance very little with change of temperature, and copies are made in German silver wire by comparison, without reference to actual length and size of wire; any required resistance is obtained by multiplication; but we must have an actual standard unit to start from. It cannot be too strongly impressed upon any one wishing to really understand electricity that he should obtain his measurements in this actual definite standard, and obtain or prepare such instruments as will be hereafter described.

209. The following Table by Mr. Varley gives a comprehensive view of the units.

TABLE VIII.—B. A. UNITS.

Subject.	Unit's Name.	Value in E. M. units.	1,000,000 units and value in E. M. units.	$\frac{1}{1,000,000}$ units and value in E. M. units.
Resistance	Ohm	10^7	Megohm = 10^{13}	..
Capacity	Farad	10^{-7}	..	Microfarad 10^{-13}
Potential	Volt	10^5	..	..
Quantity	Veber	10^{-2}	..	Microveber 10^{-8}

$$\text{Veber} = \frac{\text{Volt}}{\text{Ohm}} = \frac{10^5}{10^7} = 10^{-2}$$

$$\text{Microveber} = \frac{\text{Volt}}{\text{Megohm}} = \frac{10^5}{10^{13}} = 10^{-8}$$

$$\text{Farad} = \frac{\text{Veber}}{\text{Volt}} = \frac{10^{-2}}{10^5} = 10^{-7}$$

$$\text{Microfarad} = \frac{\text{Microveber}}{\text{Volt}} = \frac{10^{-8}}{10^5} = 10^{-13}$$

The microfarad here represents what is usually called the farad.

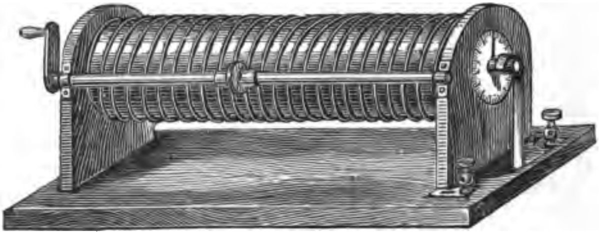
For the sake of those who may not understand these formulæ it may be well to say that the small figures mean the several "powers," or repeated multiplication by the main figure, this being here 10, it may be shortly said that the expressions mean 1 followed by as many o's as the small figure shows. Thus 10^7

means 10,000,000 (ten million); the negative sign places the 0s, less one 0, before the 1, thus 10^{-2} is ·01 (one hundredth). The index figures in fact mean that the principal figure is multiplied, or if $^{-}$, divided, once less than the index; they represent what are called the powers of the numbers, or if negative, their roots.

210. **Resistance Measures.**—These for use as weights in ordinary weighing, by comparing the unknown resistance against a known one capable of variation, § 214, are made in many forms, and most electrical works give descriptions and drawings of the earliest satisfactory instruments, Wheatstone's Rheostats, made in two forms for high and small resistance. The first consists of two cylinders, mounted on a stand, and provided with handles for winding them: the one is brass; the other wood, with a screw thread cut in it; a fine brass wire connects them, so that any length of it may be wound into the screw thread, and thus have its turns kept separate. The length thus wound on the wood cylinder measures the resistance. A great source of imperfection is that as the metal tarnishes, perfect contact with the brass cylinder is impossible, and the resistance thus varies. The wire, &c., should be well gilt to avoid this. The same remark applies to the other instrument, which, however, is much more useful than the first, if this precaution be taken to ensure the perfect cleanliness of surfaces.

Wheatstone's Rheostat.—A wooden cylinder, about 10 in. by 3 in., Fig. 50, has the wire (German silver gilt) wound upon it, either in a shallow groove, or with a separating cord cemented to the wood, in such a manner that the wire itself forms a complete projecting screw thread from end to end. Stout brass arbors are secured to the cylinder, and to one of them the commencement of the wire is connected by a stout copper strip, the other end of the wire being fixed to the wood itself. The cylinder is then mounted on a stand, and provided with a winch handle to turn it. The stand may be of wood, and upon its frame is fixed a stout gilt

FIG. 50.



copper rod parallel to the middle of the cylinder. This rod carries a traveller made of a short piece of well-fitting tube, fitted with a wheel grooved to take the wire; this wheel works in the screw thread formed by the wire, and the cylinder revolving moves it along the rod, thus including in its circuit various lengths of the wires. One binding screw is connected by a stout spring to the first arbor of the cylinder, and so through the wire and traveller to the rod, the end of which is connected by a stout strip of copper to the other terminal binding screw.

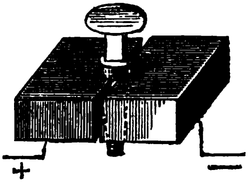
Of course there is a fixed resistance here independent of the length of wire, and the great defect of the instrument is the tendency of this portion to vary by accidental obstacles, dirt, &c., at the various points of contact. The greatest objection, however, is that it is arbitrary as to measure; it gives by reading on the bar, or on a scale, the number of turns of wire included, and by a pointer on the end the portions of a turn, but it would be difficult to make these divisions coincide exactly with those of a definite standard, such as the ohm. This may be overcome by ascertaining exactly what length of the wire equals one ohm, and then arranging a table giving the corresponding divisions. By careful adjustment of the diameter of the cylinder to the length of a wire of known resistance a very near approximation might, however, be obtained; thus, suppose a wire of about 18 gauge, when gilt, gave 20 ft. for one unit, by turning the cylinder so that it exactly received 1 ft. per turn, each turn would represent ·05 of a unit, and by marking the circle on the end in five divisions, each marked in ten, would divide the unit into 1000 divisions, the larger divisions being marked on the bar, or by means of proper wheels and another hand, upon the end plate. In this case one unit or ohm would occupy about 3 in. or 4 in. in length of the cylinder, but of course an instrument might also be made with much finer wire, and thus include considerable resistance.

A modification, enabling the instrument to measure electromotive force, is shown § 270.

211. Resistance Coils.—These are easily made up to any resistance. They are commonly mounted up in sets, giving 1000, 10,000, or 100,000 units, and are very expensive instruments. The usual plan is to make up coils corresponding to the required divisions, and connect the several terminals to massive blocks of brass arranged nearly in contact, so that a hole bored at the junction will connect the adjoining blocks when filled up by a metallic plug.

Fig. 51 shows this mode of connection, which is very largely employed in electrical instruments, telegraphs, &c., and by due arrangement of blocks gives the power of arrangement of circuit in the many instruments known as commutators, switches, shunts, &c. When the plugs are inserted, the circuit passes through them and there is no resistance; by removing a plug the current has to pass through the wire, whose ends are connected to the two blocks. These blocks are commonly screwed upon a plate of ebonite or wood, &c., standing above it: this has the disadvantage of allowing dust, &c., to collect; they should either be sunk into ebonite, which could be done before this is hardened, or else all the spaces should be filled up with pieces, so as to leave a smooth surface with no openings but the plug-holes.

FIG. 51.



To reduce the number of these connections, it is usual to make up the coils on the same principle that chemical weights are divided, viz., 1, 2, 3, 6, as by combination of these, 10, or any of its subdivisions, may be obtained; in other cases the combination of 1, 2, 3, 4 is used. These combinations have the advantage of requiring only four reels and four adjustments to each decimal series; they are therefore cheaper to make in a large way; but they are more troublesome to use than instruments with complete decimal sets as described below, as they require more arrangement of the resistances, and they are more conducive to mistakes as they necessitate the adding together all the resistances opened. In these instruments there is a complete wire circuit all through the instrument, and the plugs "short circuit," or shut off so much of the wire as may not be required. In the next form, on the contrary, there is no through wire, but such lengths as are required are thrown into circuit by a single connection for each decimal set.

212. **DECIMAL RESISTANCE INSTRUMENT.**—Consideration of the various advantages and evils of these instruments, both in principle and convenience of construction by amateurs, led me to devise an arrangement, which—writing as I do expressly to aid those who wish to construct instruments for themselves, and with the desire to furnish not merely a réchauffé of the scores of electrical books which are copied from each other, but the result of actual thought and experiment, whether in new or old ground—I will now describe. In giving its mode of construction I shall endeavour to furnish such practical observations as my own experience indicates may obviate difficulties likely to arise in the construction of instruments. The instrument described gives resistances varying from 1000 ohms to 1-1000, but for convenience of making and facility of reading, the elements are not distributed as described in last Section, but in regular decimal sets

of nine exactly similar parts, the terminal connections arranged as in Fig. 52, which represents one decimal set for any division. Each small circle represents a connection, § 213. C, the centre connection, leads either to the next series or in the last to the terminal screw. A glance will now show that the current enters at + which is connected to *o*; if this is connected to C, the circuit passes direct from this to the next series, while if C is connected to any of the numbered studs, just so many divisions of resistance are included in the circuit.

Fig. 52.

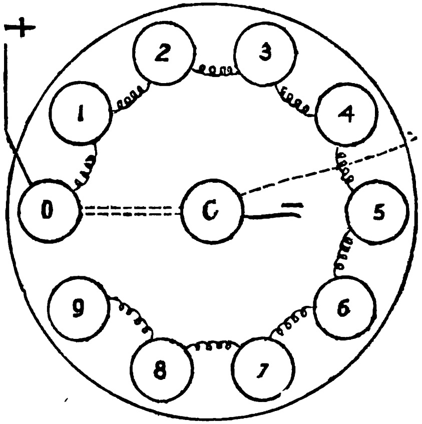


Fig. 53.

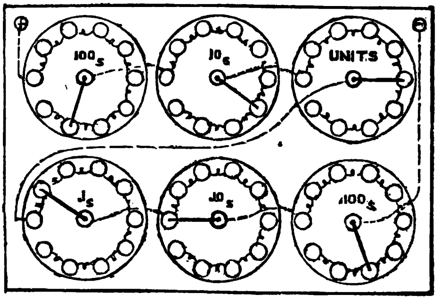


Fig. 53 will now show the complete arrangement: the upper sets represent whole numbers of units, the lower sets the decimal divisions, all arranged in the usual mode of placing figures. The resistance as it is shown, therefore, reads off 865·107 units. The dotted lines represent the fixed connections, and the path of the current may thus be readily traced through the diagram.

213. CONSTRUCTION OF RESISTANCE INSTRUMENT.—(1) *Connections.* These may be made like Fig. 51, only composed of a circular block surrounded by a ring of segmental blocks with the necessary holes to connect each segment to the centre.

They may be a central pillar with a spring traversing over a ring of studs or segmental blocks; the spring should be wide enough to pass from stud to stud without break of circuit. This plan is very quick and handy in use, but is only suited to large resistances; the varying pressure of the spring, the coating of the studs with dust or smoke, makes a great difference in the contact resistances. If employed, the spring should press strongly, and all the faces be well gilt. The best plan, but troublesome in some respects, is to use mercury cups, connected together by a bridge of stout copper wire. The cups are easily made by using for the top a thick piece of wood (say 1½ in.) and boring holes through, and filling the lower half of the holes with a copper rod or screw, the end of which, as also of the links, should be first well amalgamated. Brass screws will not do, as the mercury would penetrate them, and iron is objectionable, both for its resistance and as being likely to disturb neighbouring galvanometers. The ends of the screws which project through the wood should be first tinned, ready for soldering the wires to them. Another plan for mercury cups is shown § 179.

(2) *The coils.* The wire is usually laid upon reels; these may be of cast brass with a projecting end screwed to go into the blocks, in which case one end of the wire is soldered to the reel. If mercury cups are used, and the instrument cannot be turned over, it is better to arrange short coils horizontally, instead of longer vertical ones; fix to the middle line of the lower side of the top, a vertical board from which the proper number of rods project, and slip the reels on these. From each of the copper screws of the cups bring out to the side of the top two stout German silver wires, all arranged in order along the edge, and use these for connecting the ends of the coil wires to when mounting. The adjustment can then be made conveniently as the instrument stands, the coils being all accessible and removable. The wire, cut in lengths a little in excess of the resistance required, is doubled and laid so upon the reel; this avoids any induction in the wires, as the current is everywhere reversed, and it also prevents the coils from acting as magnets upon neighbouring galvanometers. The two ends are to be left out for connection, and in fine wires it is desirable to join a stouter wire on them to reduce risk of breaking just outside the coils. If pre-

ferred, the middle of the wire may be within the coils, so that the two ends are outward and accessible.

It is not necessary to lay the wire on reels; it may be doubled and rolled up in small coils if preferred; this has an advantage, in that it exposes more surface, and the heat of the current can escape more freely.

(3) *The wires.* These should be German silver; it is usually silk-covered, but cotton is equally good. It is desirable to saturate the covering with paraffin, by baking thoroughly dry and dipping while hot into melted paraffin. This can be done either before or after laying on reels. German silver wire varies very much in resistance, according to the amount of nickel in it. Of two wires of exactly the same gauge, No. 26, 8 ft. of the best balanced, 11 ft. 6 in. of the commoner. The following are about the lengths of 1 ohm.

No.	Weight in grains per foot.	Ohm. ft.	Ohm. in.
18	48·6	18	2·5
20	23·6	9	3·7
24	12·6	3	1·6
26	7·9	1	11·8
29	4·13	1	1·9
34	1·44	0	6·6

It is, however, quite useless to measure lengths of wire, if any accuracy is desired, because the resistance varies in each length owing to slight variations in thickness, and still more to slight changes of quality, and the finer the wire the greater this variation. Thus, in No. 18 two trials differed only a quarter inch; in No. 34 many trials gave results varying from 6·4 in. to 7·2 in. It is useless also to adjust wires before winding, as the strain upon them alters their size very slightly, and so affects the resistance, and this the more if, as should be done, the softest possible wires are used.

The size of wire is to be selected according to the purpose of the instrument. If it is to be used as an actual resistance for varying currents (and such an instrument is an essential) large wires must be used, to avoid the effects of heating by the current; if it is required only for measuring resistances with the bridge, as only small and momentary currents pass, fine wires may be employed. The following sizes are suitable:

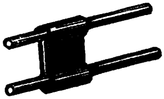
Single ohms	No. 18.	21	100 ohms ..	No. 25.	34
10 ohms	„ 20.	29	1000 „	„ 32.	40

Decimal sets need not be all of one-sized wire; the larger sizes may be used for the first coils, and finer as the resistance rises.

(4) *Adjustment.* This is effected on the principles described,

§ 218, by balancing against a standard. The ends of wire left for adjustment are well cleaned, and shortened by crossing in contact till closely correct, when they should be twisted together and soldered, and the twisting and soldering continued until it exactly equals the standard. The following is a more perfect plan, the result of many experiments. Having by mere contact, as before, ascertained closely the proper length, slide upon the two ends (first tinning them with the soldering iron) a short piece of brass tube, also tinned,* and press it together so as to grip the wires firmly. Slide the wire ends through this, watching the galvanometer till the resistance shows closely right, or a trifle too small; then touch the joint with a soldering-iron to secure it, and allow it to cool completely. The final adjustment is to be made very carefully, by lightly filing away the joint so as to lengthen the wires, or the wires themselves, so as to increase the resistance until it is correct. With fine wires it is well to join on stouter ends for this adjustment. When adjusted, the coils suspended from the top can be inserted into a case, which is to be secured by a few screws to the top, and forms the stand of the instrument. For further details of construction, see § 218.

FIG. 54.



(5) *Subdivisions of an ohm.*—These may, for ordinary purposes, be made by simple division of a length. Take 1 ohm in No. 16 German silver wire; measure carefully into 10 parts, and at each division solder a copper wire, to be taken as close up as possible to its connection. A copper or brass wire, No. 18, may be balanced against one of these tenths, and so furnish hundredths in like manner, and a length of No. 10 will give thousandths. The subdivisions may also be balanced singly by a standard ohm, using the multiplying ratios of the Wheatstone bridge.

(6) *The fixed resistance.*—The permanent connections should be made with very stout copper, the whole of the connections arranged for short circuit (that is from 0 to C), and this fixed resistance measured, and added in calculations to the resistance shown. For use with the bridge it is well to use a pair of conductors in the proper opening, and to balance against these and the fixed resistance, a length of wire which, being cut in two, is to be used to connect any resistance to the measure; then all but the actual resistance shown is neutralized, unless multiplying ratios are employed.

214. MEASURING RESISTANCES.—Electric resistances may be measured in several manners by comparing them with other resistances of known amount, but the processes resolve themselves into

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* This tinning is best done by boiling in a tin vessel with a solution of caustic soda, adding a little oxide of tin (putty powder) and some granulated tin.

two principles: (1) The comparing of *currents* produced against the resistances. (2) The comparing the *tensions* set up within the resistances. The first system may be applied: (1) By Ohm's laws, calculating the resistance from the known electromotive force and current. (2) By observing, with given battery conditions the current produced, by means of a deflection upon a galvanometer; then replacing the resistances to be measured by a set of measured resistances, and altering these until the same deflection is obtained. (3) By a differential galvanometer, as described § 182. This process depends upon the laws of derived circuits, and directly balances the currents themselves against each other.

The second principle, that of comparing *tensions* purely, without any reference to the *currents* passing, is that of the Wheatstone bridge, so called because a cross contact is produced between two points of equal and similar tension. It is also, and more appropriately, called "the balance," because that connection does as truly balance the tensions against each other as the weighing balance does the earth's attraction, or relative tensions, upon bodies on its opposite arms. It is also called "the parallelogram," because it forms a parallelogram of forces.

The principle and the use of the instrument is extremely simple; but in all the books where an explanation is attempted, it is made a very mysterious subject by being buried under two or three pages of algebraic formulæ, which make most people imagine that it is hopeless to try to understand it. The fact is, that the principle is a mere Rule-of-Three sum applied to the simple laws of derived circuits and to the distribution of electric tension in a circuit. I will state these as simply as possible, and then show how they are applied.

The law of derived circuits, § 238, is that the current will divide itself among among all the branches in proportions exactly the opposite of those of their resistances, i. e., in the inverse ratio of the several resistances.

215. The distribution of tension is equally simple, if we clearly distinguish between electromotive force and tension, with their relation to current. Electromotive force is the initial or exciting cause, be it what it may, which sets up tension; it is located at the point or points where energy takes the form of electricity. For our present purpose we may regard it as existing at the surface of the zinc plate in the liquid of a galvanic cell, and *nowhere else.* To think of electromotive force as existing in the wires, only causes confusion. But electromotive force sets up tension, or a molecular strain, throughout the whole circuit, and distributes it over the circuit in exact proportion to the resistances. This applies equally to the whole circuit or to any part of it. Now tension may be, and com-

monly is, regarded as single, and reckoned "above earth or zero," but it is better to make our notions accord with facts.

Wherever we open our circuit, we find a positive and negative condition, a + and − pole of equal and opposite tension, these being simply the opposite faces of the particles in the circuit; just as a magnet is built up of innumerable particles, having each a N. and S. face, all arranged in polar order, so is the circuit built up of polarized particles having opposite faces, which we may call + and −. It is, therefore, far better to think of tension as twofold, as representing the opposite strains or tensions of these particles. Fig. 55 presents this view, and shows how the force is distributed. A B is the circuit (which is regarded as a resistance divided into 10 equal parts), starting from the face of the liquid A C, in contact with the zinc, and returning through the negative plate (which may be anywhere according to relative resistances) and the outer circuit to the zinc plate, B D. Treating the electromotive force as a unit, and calling its value 10, we have a + and − tension, each 5, or a *difference of tensions* of 10, equal at the point of origin to the electromotive force, and drawn to the same scale as the resistance. The line C D is, therefore, the line of distribution of tension, which is likewise divided into 10 equal parts, vertical lines from which show the tension existing in any parts of the circuit. Thus from any points on the line of tensions C D, lines to the line of resistance A B will cut off a resistance equal in proportion to the sum of + and − tensions included in the intermediate resistance, and acting to set up current in that resistance.

Now let it be remembered that the actual values of the force and tensions, or resistance, are of no consequence. Let them all be great or all small, or one small and the other great, these *ratios or proportions* will hold good.

As yet we have regarded Fig. 55 as representing a whole circuit and force, but it applies equally to any fraction of a circuit. Remembering the distinction made between electromotive force and tension, yet if we take any portion of a circuit and ascertain the difference of tensions existing at the two extremities of that portion, we may regard that difference of tensions as the electromotive force operating within that portion. Let A B be only a tenth part of the circuit, then if the same unit electromotive force is considered to be acting, the actual difference of tensions constituting the force within this section of the circuit will be only 1 (equal to one-tenth of the acting electromotive force) instead of 10, but its proportionate distribution over the included resistance will remain unaltered.

But further, these same conditions apply equally if A B, this portion of a circuit, instead of being a single path, be two or many, the total current will divide itself among the paths in the inverse ratio of their resistances, no matter how these differ, and the tension

Fig. 55.

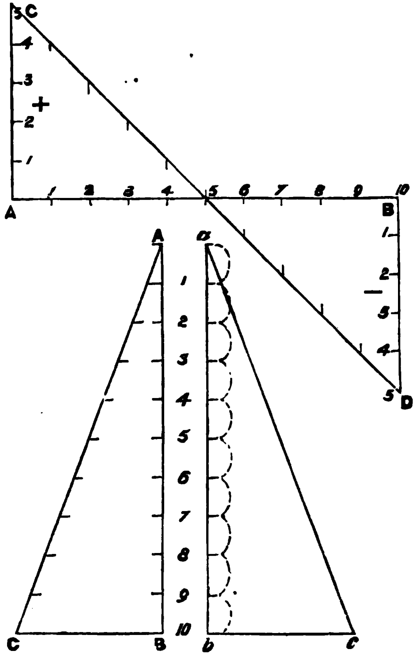


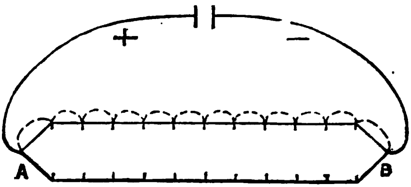
Fig. 56.

will be distributed in each circuit over that resistance in proportionate ratio. To show this, it is more convenient to treat the difference of tensions as single, instead of a compound of + and −, especially as this gives us conditions which enable us to compare electric tension with the pressure of water.

Fig. 56 represents a two-branch circuit with the several tensions, but these are not, as before, on the same scale as the resistance, but merely proportional. Let us first regard the lines A B, *a b*, as vertical pipes, connected to the same reservoir of water at an elevation which produces a final pressure B C, *b c* equal in both. Now dividing the lines of height and those of pressure, each into 10 parts, or, what is the same thing, dividing A C, *a c* equally, we get lines which represent the pressure existing at each level of the pipes; but, let us now suppose that one of these pipes, instead of being straight, goes from *a* to *c*, or that it goes to any distance away which shall lengthen its path to the level, or let it follow the dotted line between the sections; still in each proportion of length corresponding to the level of the vertical pipe A B, there will be exactly the same pressures in A B, *a b*, and *a c*. The consequence of this would be that at any such level or line of equal pressure we might make a cross-connecting pipe between A B and the other pipe, and there would be no tendency for water to pass across, and if the connection contained air, it could not escape; this would not be due merely to there being no action in the cross-pipe, for there would be action—the air in it would be subjected to an equal but opposite pressure from both sides, and would be compressed, and could not escape, even though the water were rushing through the pipes, provided the conditions were all fulfilled. But let a connection be made between, say, 2 in A B, and 5 in *a b*, and then the contained air would be pressed up towards A, and when water was flowing, some would pass along the connection.

The analogy holds when we consider A B, *a b*, to be two electric circuits, branching from one conductor at A *a*, and B *b*; the proportionate tension is the same at every equal proportional part of the resistance, and at such points connections may be made, and there will be no tendency for electricity to pass across the connection, because, although there will be such a tendency at each point, it will be met by an equal but opposite tendency at the other end of the cross-connection. This will, therefore be in the condition of a magnet, with consequent poles in its middle. A galvanometer in this cross-connection will show no current passing; an electrometer would evidence no conditions of change. This will hold true, though the one resistance be a thousand times as great as the other; still, at the definite proportional points, equal tensions exist, and no

Fig. 57.

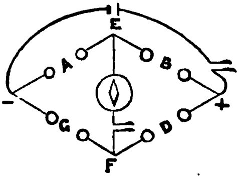


current can pass across. Fig. 57 shows the lines of Fig. 56, arranged thus as derived circuits, forming part of a main circuit from a battery.

216. **The Wheatstone Bridge**, Fig. 58, explains how these principles are applied in the ordinary bridge.

The battery wires are led to the two screws from which the two branch circuits + B E A – and + D F C – start, + and – being points of equal tensions for both circuits. E and F are fixed points in either circuit connected to a galvanometer, which indicates a current passing as long as E and F are not made to be of equal tension; it will show no action when they are of equal tension, and the conditions of balance fulfilled. There are thus four branches produced, and in each is an opening, made for the purpose of introducing such resistances as will fulfil the conditions of balance, those conditions being that the four branches shall hold among themselves the relations of the elements of a Rule-of-Three sum; as long as they do this the relations may be varied to suit each case. Let us call the resistance in each branch by the letter placed in its opening. Then

Fig. 58.



1. As B is to D so is A to C.
2. As B „ A „ D „ C.

Assuming C to be the resistance to be measured, the others being known, the rule gives its amount by two methods of arrangement; the resistance coils may be placed in A or in D, and shifted till balance is made. Then if the resistances of the other two are equal, the resistance to be measured is the same as that shown in the coil; if they hold a known proportion, such as 1 to 2 or 1 to 10, &c., the resistance is either to be multiplied or divided by that ratio as required.

It is convenient to treat one of the branches as the unknown value to be measured and C will be so used, but the law may be generalized. The resistance in (C) is to that on either side of it, as that on the other side of it is to the fourth, and reversing this expression puts it into the ordinary Rule-of-Three sum

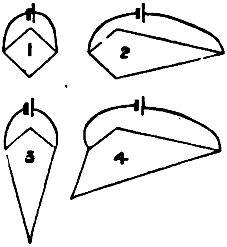
$$B : \frac{A}{D} \therefore \frac{D}{A} :: C \text{ as above.}$$

Fig. 59 shows that we have thus four arrangements at disposal:

1. Equal branches and equal circuits.
2. Unequal branches and equal circuits.
3. Equal branches and unequal circuits.
4. Unequal branches and unequal circuits.

These figures show that 1 is analogous to the ordinary weighing balance, and 2 to the ordinary steelyard; they show also by inspection which condition is the best, for throughout all nature it will be found that relations which can be expressed symmetrically are superior to those which are irregular. No. 1 is the best, and it will always be found that measurements made with all four branches alike are most accurate. No. 2 is next. These are liable only to actual errors of instruments or observations, but in 3 and 4 those errors are multiplied by whatever ratio is employed.

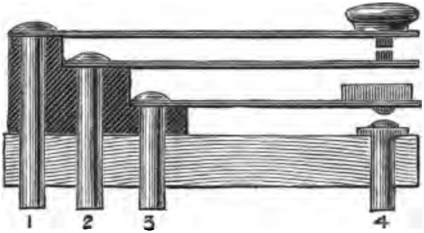
Fig. 59.



The galvanometer should be one of a resistance also approximating that to be measured, but very sensitive, the needle closely astatic and suspended by a long fibre. Of course, this element is not susceptible of much alteration, but for small resistances a good ordinary astatic galvanometer is best; for large resistances the Thomson's reflector is best suited. The law for arrangement of the galvanometer resistance is that it should equal the joint resistances on either side of it; but the best use of this law is to show with a given galvanometer what is the most sensitive arrangement of the three fixed branches. There should be, as shown Fig. 58, a commutator in the galvanometer connection, in order to prevent the needle from being thrown about by alterations in the branches; it also enables us to make contacts in time with the rate of swing of the needle and thus either to keep on increasing this swing, and so get a noticeable deflection, or by opposing the vibrations, to bring the needle quickly to rest. This commutator has also the effect of allowing any inductive actions (which for the instant act as resistances) to be completed while the galvanometer is not in circuit, and so prevent its being disturbed by them. There should also be a commutator in the battery circuit, so as to allow current to pass only just when needed, and thus avoid heating the wires. For a similar reason, as well as for economy, as small battery power as possible should be used; for all small resistances, one or two cells of a good battery will suffice, but larger resistances, of course, require more, in order to set up a sufficient difference of tension in the wires to allow a small range of resistance to send a current through the galvanometer. As only momentary currents are needed, a good manganese cell or two will answer, but an ordinary Bunsen form, charged with bichromate of potash solution and sulphuric acid, in place of the usual nitric acid, is stronger.

Fig. 58 is necessary to make the principle of construction clear, but the actual instrument need not take that form at all; so long as the two circuits are properly provided, their connections may be arranged in any way: in fact it is better not to have the galvanometer standing upon the bridge, but separate, so as not to be shaken. Thus a board 6 in. × 3 in. and a dozen binding screws will make a bridge: a piece of stout sheet copper, 2 in. square, cut across diagonally, and holes drilled near each corner to pass binding screws through, will make the two ends, and two strips 3 in. long, each containing three binding screws, will make the middle portion of the two circuits. It is still more convenient not to set the binding screws for + and −, E and F in their places, but to take connecting wires from those points and lead them to a pair of screws at one end for the battery, and a pair at the other end for the galvanometer. A still more perfect arrangement is to lead one of each of these pairs of wires to a commutator fixed on the stand, and from there to the binding screw. The best commutator for this purpose is one which makes the two contacts successively with one touch, as shown in Fig. 60.

Fig. 60.

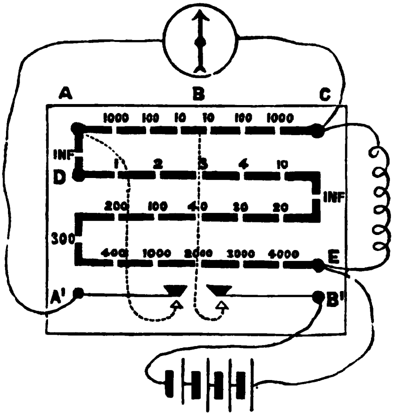


A block of ebonite or dry wood is cut with three steps, and upon each is secured a spring, having a stem passing through the block for a conductor: on the faces of the upper two springs are soldered platinum contact pieces, and also on the lower face of 3, and the top of the stud forming the fourth connection; insulating pieces of ebonite are cemented to the face of 2 and 3 to prevent contact: 1 and 2 form part of the circuit from one of the battery binding screws to the + or − point of the bridge. 3 and 4 are in the same way part of the circuit from E or F to one of the galvanometer screws.

We have thus an excellent skeleton of the bridge, which requires the means of filling up the openings A B D to complete it; one of these is, of course, a resistance coil, §§ 211–213. For the other two openings we require simply two equal or proportional resistances, which may be mere lengths of wire, but should be two properly fitted resistances, variable as required. The best is a set made exactly as described for the resistance instrument itself, containing 1, 5, 10, 50, 100 ohms, and so on, as required, which being made all continuous, require coils 1, 4, 5, 40, 50, and so on, with the power of throwing the required length into circuit. The best plan is to combine all these resistances and the bridge in one instrument.

217. Combined Bridge and Resistances.—Fig. 61 shows the ordinary post-office pattern arranged to act as a bridge. The right-hand commutator is that of the current, from which it will be seen the circuit goes to the middle of the upper line, which is the two variable resistances (as in B D, Fig. 62), when the left-hand plug marked Inf. is removed. The resistances from D to E are the branch A, Fig. 58, and between C and E the branch C, the resistance to be measured. The uses of the instrument are the same as that to be next described. When both Inf. plugs are in place the instrument can be used as a direct resistance throughout. Its relative advantages and defects are shown, § 211.

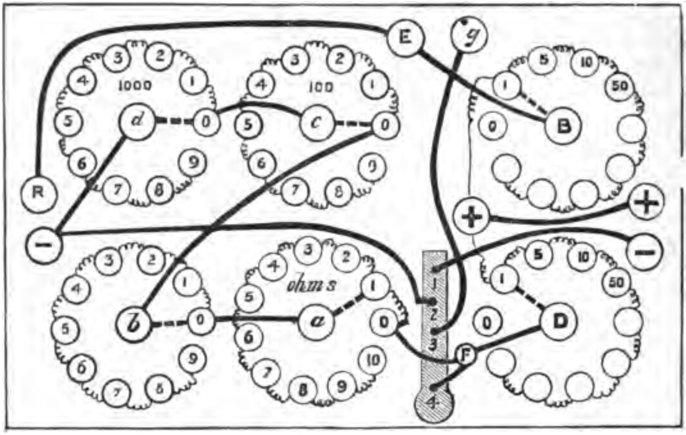
Fig. 61.



218. Decimal Combined Bridges.—Fig. 62 shows such an instrument, devised upon the principles of the resistance instrument § 212. The lettering of the parts corresponds to that of Fig. 58, so that it is easy to trace the connections and the manner in which they fulfil the conditions of the bridge. + and – are the binding screws for the battery wires, and their connection may be traced to + within the instrument, and through the commutator to – at the other end, these being the points at which the real bridge (the derived circuits) commences. B and D are the two variable

resistances of each circuit, one of which, D, is continued through *a*, *b*, *c*, *d*, the resistance measure ranging from 1 ohm to 10,000:

FIG. 62.



the other branch goes direct to E, and is then continued to R, which forms with − the connections for the resistance to be measured, and thus constitutes the fourth branch. The neutral points E'F are connected to the galvanometer screws, one direct, the other through the commutator to *g*, which with E is the connection to the galvanometer. The instrument is shown as arranged for ordinary measurements, as though measuring a resistance of 1 ohm; by means of the multiplying ratios it would measure a million ohms or the thousandth of an ohm. It may also be employed as a direct resistance through R and −.

In the diagram there are 9 coils to each set except the single ohms, it having been designed from the resistance instrument, § 212, which has three other sets for dividing the ohm to thousandths, which sets can easily be added to this if desired. In the present instrument perhaps it would be an advantage to divide the circles into 11 parts, so as to make each set a complete decimal unit without throwing any others into series. This is done with the single-ohm set, as otherwise there would always be some difficulty in making up even numbers, and there would be 1 ohm short of the 10,000.

The mode of construction is identical in principle with that described, § 213; but the explanation is given here how to carry this into effect, so as to build up the complete instrument accurately from a single standard ohm, where the maker has not another instrument to copy. A temporary bridge, such as is described, § 216, is required, and at least four exactly similar wires as conductors for use in the openings A C; two similar wires should be soldered to F and + within the instrument unless mercury cups or binding screws are inserted there, as these are the starting points of the various resistances. To avoid confusion in the lettering, during the rest of this description the letters which relate to the temporary bridge will be enclosed in brackets.

Connect the battery and galvanometer to the bridge, and place the standard ohm in (A) with two wires of near an ohm resistance, and as nearly as possible alike in (B) and (D); and in (C) a wire, which make to balance the ohm. Now change the wires in (B) and (D) one for the other; if they were exactly alike (A) and (C) should still balance; if they do not, shorten one of the wires (B D) till balance is again produced, and ascertain the exact difference of length necessary for the purpose; shorten the wire by *half* this length and readjust (C); now, if care has been taken, balance will be undisturbed when (B D) are again exchanged. In all cases this must be ensured before any reliance can be placed upon measures taken. Make in (C) two exactly similar ohm coils which should be terminated, not with binding screws, but with No. 10 copper wire, to go into the screws of (B D), and ascertain as before, by exchanging, that they are exactly equal, as on this will depend the accuracy of the instrument; they may be incorrect ohms if it so happens, but they *must be exactly alike.*

These being in (B D) connect the standard in (A) by two of the equal conducting wires, and by two others connect (C) to F and + in the instrument, and adjust the coil of D 1 to one ohm exact, inserting the shifting connection as shown. Then insert the connecting wires from (C) in 0 and 1 of *a*, and adjust the first ohm coil, the two ends of which are soldered to those connections; if mercury cups are used, this is done by amalgamating the ends of the conductors, and dipping them into the cups, or two of the conducting wires can have plugs on one end if plugs are used;* if other connections are used, a copper wire should be attached to each long enough to be conveniently attached to and form part of the conductors. Repeat this with each of the ten separate ohms, adjusting them one by one.

Now disconnect the standard ohm and insert the two wires from (A) in *a* 0–5 and those from (C) in + and F as before, and adjust

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* In this case it will be desirable to have holes bored *in* the segmental blocks (corresponding to Fig. 51) forming the ring of connections, by which to make direct connection to each separate coil: screws may afterwards be passed through these holes to secure the blocks to the top of the instrument.

D 5. Then including *a* 0 to 10 in (A) make in (C) two approximate 10-ohm coils. Place these in (B D) of the bridge, with the same precautions as before of exchanging and equalizing them, and make a correct 10-ohm coil for use in (A) of the bridge. Using this as the standard ohm was used, go through exactly the same stages as before, and so adjust D 10, *b* 1 – 10, and D 50. When this is done, *a* and *b* together will furnish the basis for a 100-ohm coil, allowing in the connecting wires for the extra resistance of the fixed connection between *a* and *b*. Go through the same process with *c* and *d* till the whole 10,000 ohms is built up and those of D completed to such extent as is desired. The coils of B may be also adjusted at the same time, and in a similar manner with those of D, by using the E connection instead of F; but it will be much better to balance them direct by the instrument itself against those of D by connecting in turn in R – the standard, 10, 100, and 1000 ohm coils, and opening equal resistances in *a*, *b*, *c*, *d*. The fixed connections shown in thick lines are secured to the lower face of the top, and as they form the closed circuit of no (measured) resistance from F to –, they should be of the stoutest copper convenient, such as No. 10 doubled, as this resistance is a source of inaccuracy with multiplying ratios. The connection between R and E is to be also of copper, and to exactly balance the other connection, by putting F – (the movable connections being all on *o* of each set) in (A) of the bridge and E R in (C), and adjusting the length of this to balance. This should be done before adjusting the coils. If great accuracy is desired, this resistance should also be measured once for all, and a correction made for it in observations when a multiplying ratio is employed. If all is correct, with 1 ohm in R and – (connections in the ohm) and one ohm in B, *a b c d* ought to balance the ohm, or such multiples as D is set at, should be required; which last is unlikely to be exactly realized by any one not well practised in adjusting. In each of the sets, care should be taken that any little residual errors should be alternately opposite, so as to rectify each other as the resistance increases, instead of the error accumulating. While adjusting, the greatest care must be taken not to hold the wires in the hand, or to expose them to any unequal heat; and when that is necessary, as in soldering, to allow them to cool perfectly, otherwise the resistance will be wrong.

In using this, or, indeed, any form of bridge, it is desirable to make it a rule to always connect the battery and galvanometer in one way, so that the deflection at once tells whether the resistance is too great or too small. When exact balance cannot be obtained, as when part of an ohm is required, observe with a resistance too great and one too small the opposite deflections produced; the difference between them will show how much to allow.

219. **The British Association Bridge.**—This is a special form devised for adjusting units. It is provided with a length of platinum iridium wire, with a scale and a moving clamp which corresponds to the point + in the previous figures; it, in fact, by slightly moving on the wire, alters the relation of B and C, and serves the purpose of the plan described for correcting erroneous wires; as long as A and C are unequal the clamp has to be moved to one or other side, but when they are made equal, the clamp has to occupy the middle of the scale. A full description with drawings is given in the 'Reports of the Committee on Electric Standards.'

There are also a great variety of forms made for different purposes, but the principle is alike in all.

Condensers of known capacity may be used in the branches instead of the resistances, and an electrometer in place of the galvanometer; but this plan is employed only in connection with long submarine cables.

CHAPTER VI.

CONDUCTIVITY AND RESISTANCE.

220. These terms are the converse of each other, but there is this important difference—*Resistance* is absolute and measurable in standard or other definite units. *Conductivity* is only relative or abstract; though it is usually stated as relative to copper as a standard, still this is only relative as it fixes no dimensions. Conductivity can be ascertained only by ascertaining the actual resistance in a given case; then by calculating what would be the resistance of pure copper in like conditions, we obtain the relative conductivity of the substance examined.

221. Specific Conductivity.—Under the same conditions of dimension, different substances offer very different resistances; that is to say, each molecule requires the exertion of a definite force to break it up, and the action takes place quickly or slowly under equal force according to the specific power of resistance. This is a pure matter of observation and experiment, and our most reliable authority is Mathiessen, from whose labours most of the information in Table IX. is derived. Col. II. is the specific conductivity, silver being taken as a standard.

Alloys usually have a higher resistance than that of the mean of their components, which appears to indicate that an actual chemical combination has occurred, not a mere mixture of the metals. This property even affords a means of classifying alloys as of these two orders; thus the alloys of tin and lead differ slightly from the mean, while that of tin and antimony has only $\frac{1}{30}$th of the mean conductivity, indicating a much closer combination. Other physical properties attend this classification.

Alloys are also affected by heat, as to their conductivity, differently from pure metals, which it will be seen renders some of them very useful. Particulars are given in Table IX., below the pure metals, of a few of the most useful alloys. As a consequence, ordinary commercial metals (which are always alloyed with foreign matters) have a higher resistance than pure metals, a fact of great importance as regards copper.

222. HARDNESS generally increases the resistance of metals; this shows that transmission of electricity depends upon molecular condition, for hardness is a state of stronger cohesion and rigidity, and therefore of less freedom of motion; annealing diminishes this strain, and allows a readier motion of the molecules among themselves, and this also allows electricity to pass more freely. This is shown in the table. As time and the passage of electric current produce a softening effect, it is important to use soft wires in instruments whose resistance is to be constant, and wherever it is required to be low, as in galvanometers. Soft wire is also much more easily arranged.

223. CONDUCTIVITY AND HEAT.—As a rule, the conductivity of metals varies in the same manner for both forces—a very strong indication that the modes of transmission are similar, and that the forces are of similar nature.

Variation of temperature has a remarkable influence on the conductivity of bodies. As a rule, the resistance of liquids diminishes as the temperature rises, while that of metals increases. A glance at Columns IV., V., and VIII. of Table IX. shows that the influence on pure metals is nearly uniform, not as regards their actual, but their relative resistance. Thus, whether a metal have a high or low specific resistance, that resistance increases in almost exactly the same ratio—for instance, bismuth and copper (Column V.)—and it is very probable that slight differences shown are really due to some impurity in the metals, which are not readily obtained in perfect purity. Column VIII. is taken from Fleeming Jenkin, as also VI. and VII.

Mercury, however, is an exception, owing to its liquid condition, no doubt; and its slight variation is an additional element of advantage in treating it as a standard for units.

But alloys differ from pure metals in being much less affected by change of temperature, which, together with their greater resistance, renders them suitable for measures.

As the current itself heats the wire, the resistance varies from this cause just as though the heat were external; and it is important, therefore, in measuring resistances to use a low power. The mode of correction for the effect of temperature is given in § 229.

224. LAWS OF RESISTANCE.—In a conductor of uniform quality and form, resistance varies *directly as the length;* for, if we double the length, we double the number of molecules to be acted on. It varies *inversely as the sectional* area; for if we double this, we double the number of molecular chains which offer a path. This latter fact may be variously expressed, it may be said to vary inversely as the weight in a given length, for this increases as the section does, or we may say it varies as the square of the diameter

of the conductor, for the sectional area increases as the squares of the diameters.

These laws apply to all conductors, liquid or solid, but it is to wires that their application is most direct and important.

TABLE IX.—CONDUCTIVITY AND RESISTANCE OF METALS.*

I.	II.	III.	IV.	V.	VI.	VII.	VIII.
			Loss of C. at 212° compared with 32°		Resistance at 32° Fahr. of 1 ft. of wire		Variation per cent. for 1° Fahr.
Metals Pure.	Silver at 32° = 100.	Relative resistance.	actual.	per cent.	weighing 1 grain.	of 1 mil diameter.	
Aluminum	33·76	2·96	..	..	·1085	17·72	..
Antimony	4·62	21·65	70·54	29·46	3·456	216·00	·216
Arsenic	4·76	21·01	69·88	30·12	..	..	..
Bismuth	1·25	80·00	70·51	29·69	18·64	798·	·196
Cadmium	23·72	4·21	70·70	29·30	..	..	..
Cobalt	17·22	58·07	..	..	..	..	..
Copper, hard	99·95	1·00	70·31	29·69	·2106	9·940	..
„ soft	..	..	..	..	·2064	9·718	·215
Gold	77·96	1·28	71·70	28·30	·5849	12·52	·202
Iron, hard	16·81	5·95	..	..	..	..	..
„ soft	..	..	..	..	1·097	59·10	..
Lead	8·32	12·02	70·39	29·61	3·236	119·39	·215
Mercury	1·63	61·35	..	..	18·720	578·6	·040
Nickel	13·11	7·63	..	..	1·535	75·78	..
Platinum, soft	18·03	5·55	..	..	2·810	55·09	..
Silver, hard	100·	1·	71·56	28·44	·2421	9·936	·209
„ soft	108·57	0·92	..	..	·2214	9·151	..
Thallium	9·16	10·92	68·58	31·42	..	..	..
Tin	12·36	8·09	70·11	29·89	1·396	80·36	·202
Zinc, pressed	29·02	3·44	71·23	28·77	·5831	34·22	·202
Alloys.							
Brass .. .. about	20·	5·	..	..	..	..	..
German silver „	12·to 16·	6·to 8·	..	..	2·652	127·32	·024
†1 Silver, 2 Platinum	..	..	..	..	4·243	148·35	·017
1 Silver, 2 Gold	..	..	..	..	2·391	66·10	·036
Steel .. about	16·	6·to 25·	..	..	..	..	..
Graphite	0·69	145·	..	..	..	..	..

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* From recent experiments it would seem that light has an effect upon conductivity in some cases, but it has been observed only with selenium. Lieutenant Sale gives the following figures as the resistance of a bar of selenium in darkness, and under different parts of the spectrum:

In darkness	330,000	In green	278,000
violet	279,000	blue	279,000
red	255,700	diffused daylight	270,000
orange	277,000	bright sunlight	165,000

† B A standard units are made of this alloy.

225. **WIRES AND THEIR PROPERTIES.**—It is essential to those using, and still more so to those making, electrical instruments to obtain thorough information as to the properties of wires, especially

of copper. To this end many of the published books contain tables and a collection of formulæ; but anyone who tries will find that it is impossible to obtain concordant results from the various formulæ. A similar difficulty arises in practice. Wire is usually bought by Birmingham wire-gauge. Here is, however, a name without an object belonging to it; for no human being can tell what the Birmingham wire-gauge is, and different dealers will differ two or three sizes, while, in the finer wires, it is a mere chance what will be obtained for any gauge asked for.

When gauges are mentioned in this work, the size meant is that given in Col. I. of Table II., which are those given in Culley's work, these being commonly accepted among electricians. The remedy for this confusion is to abandon the gauges altogether, and fall back upon definite principles, of which there are two available (1), the measured diameter of wires; (2), the weight in a given length. This latter is already employed on the large scale, as in contracts for telegraphic purposes. All who wish to work satisfactorily should adopt one of these plans, and purchase their wires, not by gauges, but by definite measured diameters, or by their weight in a given length, such as per foot or yard.

In showing how to apply these principles and in the formulæ for the purpose logarithms are used, because this is the simplest mode of calculation, as well as the most accurate, rapid, and least fatiguing to the brain; their use cannot be too strongly recommended to those who have to make many calculations of any kind. The examples and formulæ having their decimal values given as usual can be worked out in the ordinary manner by those who prefer to do so.

226. For electrical purposes, in addition to the ordinary commercial considerations of weight, length, and strength, we must include electric resistance, the laws of which are given in § 224, so that if we fix upon a definite unit, which includes weight, length, and resistance, all considerations are resolved into mere multiples of that unit.

Although we may buy and speak of wires by their diameters, this principle means that we should think, not of their diameters, but of their sectional area, which varies in the ratio of the square of the diameter; we must, in fact, regard the wires, not as single cylinders, but as though they were built up of a series of parallel unit cylinders of definite properties. Of course, the metric measures would furnish the best system, but as this is practically out of the question, the best plan available is to take for the unit of measure the one-thousandth of an inch, already frequently so used, and called a "mil." Since wires are round, and the areas of circles increase as the squares of the diameters, we should regard the "mil" as a circular wire. Then, by squaring the diameter in "mils" of any wire, we obtain direct its area in circular mils,—that is to say, the number of unit wires to which it is equivalent. To make the unit complete, its length must be defined, and the foot is the most convenient measure. But as in electricity we require to include in our unit electric resistance as well as the weight, &c., it is still more convenient and generally useful to make weight, rather than diameter, the basis of the unit and the most generally useful unit would appear to be a wire, 1 foot long, weighing 1 grain. By ascertaining the relation of this, for each metal, to the general circular *mil* foot, every necessary calculation can be readily effected. This relation is given as nearly as present knowledge allows in Cols. VI. and VII. of Table IX., p. 178.

A wire is simply a cylinder occupying a certain measurement of space; the weight of the cylinder will depend upon the specific gravity of the material which fills the space.

A cubic inch of water weighs 252·456 gr., and this multiplied by 12 and by ·7854 gives us the weight of a circular inch-foot of water; and that multiplied by the specific gravity of any metal gives the weight of a circular inch-foot of that metal, and thus the datum for all required calculations. I will work this out in logarithms, taking, as the basis, copper, specific gravity 8·9, this being the average specific gravity of good copper wire:

Cubic inch of water 252·456 ..	2·4021857	
12 in. per foot	1·0791812	
·7854, ratio of circle to square	$\bar{1}$·8950909	
Circular inch-foot of water ..	3·3764578	= 2379·3
Specific gravity of copper, 8·9	0·9493900	
Circular inch-foot of copper ..	4·3258478	= 21176·1

This divided by 1,000 × 1,000 = 1,000,000, gives the weight in grains of a wire of a circular *mil* one foot long. In this way are obtained the figures in Column II. of Table X. of the various constants required in calculations as to wires.

By dividing 1,000,000, the circular *mils* in an inch, by the weight of the circular inch-foot, we obtain the sectional area in *mils* (or number of *mils* it occupies) of a wire weighing one grain per foot. This gives Column III. of the Table of Constants.

1,000,000 = 10^6	6·0000000	
Inch-foot of copper, 21176·1 ..	4·3258478	
Mils per grain-foot, G. ..	2)1·6741522	= 47·22
sq. root		
Diameter of grain-foot	0·8370761	= 6·872

Assuming as correct the resistance of one foot-grain wire given in Table IX., we obtain all that is necessary to complete the data, viz. the resistance of the unit foot-grain wire, which I have calculated at 60° and inserted in Column IV. of Table X.

Resistance of one foot-grain soft
copper at 32°, ·2064 .. .. $\bar{1}$·3147097
Correction for 28°, 1·0505 .. 0·0255107

Unit resistance at 60°, U... .. $\bar{1}$·3402204 = ·21889

This unit wire, one foot weighing one grain, and having, as pure soft copper, a resistance at 60° Fahr. of ·21889 ohm, will now furnish any information needed by simple processes of calculation.

Let the following symbols represent the several elements:

d, diameter in *mils.*
d^2, square of d = sectional area in circular *mils.*
w, weight in grains per foot.
l, length in feet.
M, grains per *mil*-foot of the metal, Column II. of Table X.
G, area in *mils* (d^2) of unit grain-foot, Column III. of Table X.
U, resistance in ohms of unit wire, Column IV. of Table X.
R, measured resistance at 60°.

TABLE X.—CONSTANTS OF UNIT WIRES.

	I. Specific gravity.	II. *M* Grains per *mil*-foot.	III. *G* Area in *mils* per grain-foot.		IV. *U* Resistance at 60° Fahr. of foot-grain.	
			Mils.	Logarithm.	Ohms.	Log.
Copper	8·9	·0211761	47·22	1·6741522	·2189	$\bar{1}$·3402204
Iron	7·8	·0185590	53·88	1·7314476	1·1634	0·0657173
German Silver	8·7	·0207003	48·31	1·6840229	2·6699	0·4264939
Brass	8·4	·0199865	50·03	1·6992629	·9938	$\bar{1}$·9972763

Calculations would require a correction for conductivities varying from those given, or it would be simpler to obtain a new constant in place of U for any wire of which the actual conductivity is known.

227. FORMULÆ OF WIRES.—I. *To ascertain the* DIAMETER, d, *of any wire*, weigh and measure carefully any convenient piece, and reduce to grains per foot. Multiply this by the constant G in Column III. (47·22 for copper). This gives the sectional *area* in *mils* d^2, and the square root of this is the diameter in *mils*, d.

$$d = \sqrt{w\text{G}}.$$

Ex. 4 ft. weigh 3·15 grs.	0·4983105	
Divided by 4	0·6020600	
w, grains per foot	$\bar{1}$·8962506	= 0·788
G, constant for copper, 47·22 ..	1·6741522	
d^2, sectional area	2)1·5704028	= 37·10
d, diameter in *mils*	0·7852014	= 6·1

For other metals the proper constants should be used.

II. *The diameter being known, to ascertain the* WEIGHT *of any length, or the* LENGTH *of any weight;* multiply the square of the diameter by Column II. of the Table, the grains per *mil*-foot. This gives the weight in grains per foot, from which all required weights and lengths are ascertainable by common arithmetic.

$$w = d^2 \mathrm{M}.$$

Or, dividing the square of the diameter by the area of the grain-foot G, Column III., will also give the grains per foot.

$$w = \frac{d^2}{\mathrm{G}}.$$

The square of the diameter, by using the following constants, will give the particular information, in each case, for copper wire.

	•	Log.
Feet per pound, divide by d^2 ..	330560	5·5192502
Yards per pound, divide by d^2	110187	5·0421289
Grains per foot, multiply by d^2	0·0211761	$\bar{2}$·3258478
Pounds per 1000 feet, multiply by d^2	0·0030252	$\bar{3}$·4807498
Pounds per mile (English), multiply by d^2	0·015973	$\bar{2}$·2033837
Pounds per nautical mile, multiply by d^2	0·018414	$\bar{2}$·2651531

The same constants, used in the opposite manner, will give the area, and hence the diameter of a wire, of which any of these particulars are known.

III. *To ascertain the* RESISTANCE *of any wire at* 60°, divide the unit resistance U, Column IV., by the weight in grains per foot. This gives the resistance per foot, which multiply by length required.

$$\mathrm{R} = \mathrm{U} \times \frac{l}{w}.$$

Or, multiply U by the length in feet, and divide the product by the area multiplied by M, the grains per *mil*-foot.

$$\mathrm{R} = \frac{\mathrm{U}\,l}{d^2\,\mathrm{M}}, \text{ or } \frac{\mathrm{U}}{\mathrm{M}} \times \frac{l}{d^2}.$$

This last formula gives another constant, the resistance of the *mil*-foot at 60°, which might, if preferred, serve as the principal unit instead of the grain-foot.

The foregoing formulæ are applicable to all the metals, using the proper constants; but the following constants, for special purposes, apply to copper only. They are, in fact, the resistances of a wire of one-thousandth inch diameter of the length named at 60°, and are to be divided by the sectional area in *mils*, d^2.

		Log.
Ohms per foot at 60°	10·3365	1·0143726
Ohms per yard	31·0095	1·4914939
Ohms per mile	54,577	4·7370065
Ohms per nautical mile at 60°	62,918	4·7987759
For ohms per pound divide by d^4 or the square of the area $(d^2)^2$	3,416,825	6·5336228
For feet per ohm multiply d^2 by	0·0967447	$\bar{2}$·9856274

IV. *To Measure Conductivity.*—Measure the resistance of any convenient length, correcting for temperature to 60°. Divide by the length in feet, and multiply by the weight in grains per foot. This gives the resistance per grain-foot, by which divide the unit 0·21889. The quotient is the conductivity.

$$C = U \div \frac{R\,w}{l}.$$

The actual measurement of wire for its resistance, in order to ascertain its conductivity, may be effected on three distinct systems.

(1) The measurement of any length and reducing the length and resistance to the unit foot-grain, or mil.

(2) By Clark's system. A standard wire of copper is mounted, its length or size is of no consequence, but its resistance is made 0·1516 ohm at 60°, being equivalent to a wire 100 in. long weighing 100 grains; the conductivity of any other wire is measured direct by balancing the necessary length against this, and will be as the square of its length in inches divided by its weight in grains. This has the advantage of requiring no correction for temperature, as both the wires vary alike, care of course being taken not to so pass current through as to act unequally on them.

(3) By a pair of stout clamps, forming one of the openings of a Wheatstone's Bridge; the resistance per foot is thus measured, and multiplied by its weight in grains, gives the actual foot-grain resistance.

Example.—The 4 feet of wire, weighing 3·15 grains, used as the first example, gave a resistance, at 72°, of ohms, 1·349.

Resistance, 1·349	0·1300119
72 − 60 = 12°, correction, 1·0255 ..	0·0109357
R, resistance at 60°	0·1190762 = 1·315.
w, grains per foot, 0·788	$\bar{1}$·8962506
	0·0153268
l, length 4 feet	0·6020600
Res. per grain-foot at 60°	$\bar{1}$·4132668 = 0·25898.
Unit grain-foot resistance, 0·21889	$\bar{1}$·3402204
Actual grain-foot resistance, 0·25898	$\bar{1}$·4132668
Conductivity	$\bar{1}$·9269536 = 84·5 per cent.

Or, measure and weigh any length of which the resistance is known, and multiply U by the length, and divide by weight per foot, which gives the equivalent resistance as pure copper, which divide by the actual resistance.

As the foregoing formulæ differ in several points from those generally given to attain the same results, it may be explained that this is owing to the definite system of which these form a part. Most other formulæ are single ones, devised each for its own purpose, and often based upon mere actual measures of particular wires, which often vary in quality. Those given here may have no actual superiority over these others, except as forming part of a definite system based upon mathematical truths, and linked especially to the conception of wires, not as each separate entities, but as consisting of collections of unit wires of definite property, thus giving to d^2 an extended meaning, from the mere square of the diameter of single wires to the number of units in all wires.

228. COPPER WIRE.—This varies very greatly in its electric properties, ranging in conductivity from 97 per cent. as low as 50. It is of great importance to attend to this, for in making an instrument, be it a galvanometer, an electro-magnet, or a coil, resistances should be duly balanced with the battery power employed, while it is of great importance not to use wire unnecessarily large, because this increases cost and diminishes the effect; so that by not attending to this we may obtain only half the effect we should by securing good wire.

Pure copper is the theoretical standard, though what it is, and how to be obtained, seems puzzling from the following experiments of the most careful experimenter on the subject, Matthiessen; and from the peculiar properties of copper, it would seem that silver, which is more free from objection, should have been taken as standard.

Matthiessen gives the relative conductivity of various coppers as compared with hard-drawn silver:

Pure copper:		Temperature.
Oxide reduced by hydrogen	93·0	at 18·6 C.
Electrotype, not melted	93·46	„ 20·2 „
„ fused in hydrogen ..	92·76	„ 19·3 „

The conducting power increased about 2 per cent. by annealing the wires.

Impure, or commercial coppers:		Temperature.
Containing red oxide, melted in air ..	73·32	at 19·5 C.
Containing 0·95 per cent. of phosphorus	23·24	„ 22·1 „
Containing 2·80 per cent. of arsenic	13·14	„ 19·1 „
Containing 1·60 per cent. of zinc ..	56·98	„ 10·3 „

Taking the pure unmelted electrotype copper as standard, or 100,

Spanish (Rio Tinto), containing arsenic, iron, lead, &c., was	14·24
Russian, with traces of same	59·34
Tough cake	71·03
Australian, Burra Burra	88·86
American, Lake Superior	92·57

These figures show that excellent commercial wire may be very bad for electrical purposes.

229. CORRECTION FOR TEMPERATURE.—It is convenient to adjust resistances at the ordinary temperature, 60° Fahr., for which reason, also, the values are given in the formulæ and tables at that point. But it is necessary for many purposes to know the resistance corresponding to a temperature different from that at which observations are made, for temperature plays a very important part in the resistance of wires; in fact, it is difficult to get the same resistance twice for a piece of copper wire, if it is touched, or if the slightest change takes place in the room. Tables of correction are given in many works, but they never point out that these tables only give a part of the correction required; they deal only with the temperature of the wire itself, but leave out of sight altogether the variation which takes place in the *measurement instrument itself*, though this is one-tenth of that of the copper wire as regards external temperature, and greater than that of the wire as regards any heat produced by the current itself. The latter cannot be well dealt with except by careful valuation in each case; but for ordinary resistance measurement, with small and momentary currents, the external action alone need be considered. Instruments for measuring resistance ought to have marked upon them

the temperature at which they are correct, then the correction for actual temperature, say in copper wire, would be, not that for copper merely, as given in the usual tables, but this less the simultaneous variation of the German silver wire of the instruments. Thus for each degree Fahrenheit near about 60°,

Copper varies as 1 to	1·00215	log.	0·0009327
German silver varies as ..	1·00024	„	0·0003126
Combined correction at 60° ..	1·00191	„	0·0008287

The variation occurs not equally for each degree, but by a curve represented according to the experiments of the British Association Committee on Electrical Standards, by the formula for the resistance R at temperature t (Centigrade) from the resistance r at zero, $R = r\,(1 + a\,t \pm b\,t^2)$.

	a		b
Pure metals	0·003824	+	0·00000126
Mercury	0·0007485	−	0·000000398
German silver	0·0004433	+	0·000000152
Platinum silver	0·00031		

But for all ordinary purposes the correction above given will suffice, multiplying the decimal portion or the logarithm by the number of degrees (not by the logarithm of the degrees), and multiplying the resistance observed, for higher temperature, and dividing for lower temperature; adding or subtracting, as required, the logarithmic correction to the logarithm of the observed resistance.

Thus to correct from 60° to 32°, or the freezing point (zero Cent.) is 28° ·00215 × 28 = 1·0602 for copper. The correct figure, 1·0605, differs very slightly from this, and the mode of correction is shown in the third calculation, § 226.

230. Table of Copper Wire.—This is calculated on the formulæ, § 227, for the most useful sizes of copper wire, but its readings may be translated into the values of other metals by the following constants (Table XI., p. 188):

			Log.
1. Weights. Multiply by	Iron	·87641	−1·9427046
	German Silver ..	·977538	−1·9901293
	Brass	·94382	−1·9748893
2. Lengths. Multiply by	Iron	1·14003	0·0572954
	German Silver ..	1·02298	0·0098707
	Brass	1·05952	0·0251107
3. Resistance, Multiply by	Iron	5·3149	0·7254969
	German Silver ..	12·2009	1·0863826
	Brass	4·54	0·6570559

4. Length of Resistance (Col. IX.) divide by the foregoing constants, which are the conductivities, copper being 1. In like manner the conductivity of any commercial copper or other metal will give the correction to employ.

The data chosen have been those most extensively available; thus 1000 feet is taken because the change of the decimal point converts the value into that of 1, 10, or 100, while multiplying by 5·28 converts it into a mile. The last column is likely to be very useful to those who wish to select wires for any purpose, especially as multiplying by 12 gives very closely the value in German silver. The figures in the foot-grain and mil lines are the constants for use in the formulæ. The diameters are shown in millimetres for comparison when required. The millimetre and metre-gramme lines give constants which enable calculations to be made for wires measured on the metric system, in the same manner as is described for the foot-grain system.

231. Resistance and Work.—It has already been mentioned that under the general idea of resistance may be, and is, included every action and property which opposes the passage of a current, and that every such action may be definitely measured in units of resistance. In fact, when a circuit is once closed and its resistance measured, that resistance will vary every instant, not only in the battery, owing to the chemical changes, but in the conducting wire itself. We have already seen that change of temperature (even though caused by the current itself), alters the resistance; but, in addition to this, any work added to the arranged circuit, without any change in the circuit itself, has exactly the same effect. This is a difficulty to many minds, though it is an obvious matter to all who have thoroughly grasped the doctrines of the conservation and correlation of energy which are the sure foundation on which modern science is now building.

The general principle is that every effect must have its adequate cause, therefore every action involves an equivalent expenditure of force, and of those materials from which we derive our force. When a circuit is once formed, a condition of equilibrium is set up between the resistance and the force expended, and the battery exerts every fraction of force the resistance permits; evidently, then, if we add any work, either the battery action must diminish, or we must give it more force, and expend material sufficient to do the required work. The exact relations will be considered under the laws of current, but a simple experiment will convey the facts and principles.

I divided one ohm of No. 20 wire (about 83 ft.) into four equal parts, and wound them on two coils, two wires side by side in each, making 97 turns for each wire, the coils being 2½ in. long on a core of half an inch. These were intended for experiments in electro-magnetism, but they furnish the means of balancing two circuits on the Wheatstone bridge, and testing the resistances under various conditions, by eliminating every action but the one to be examined—

TABLE XI.—PROPERTIES OF COPPER WIRE. SP. GR. 8·9.

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
B. W. Gauge.	Diameter.		Sectional area in circular Mils. (d^2)	Weight.		Length.	Resistance as Pure Copper at 60° Fahr.		
Common.	In Mils. =·001 in. (d)	Milli-metres.		Grains per foot. (w)	Pounds per 1000 feet.	Feet per pound.	Ohms per 1000 feet.	Feet per Ohm.	Ohms per pound.
inch. ¼	250·	6·37	62500·	1323·5	189·07	5·29	0·1654	6046·5	·00088
6	200·	5·08	40000·	847·1	121·01	8·26	0·2584	3869·8	·00214
	180·	4·57	32400·	686·1	98·02	10·20	0·3190	3134·6	·00326
8	170·	4·31	28900·	612·0	89·46	11·18	0·3495	2861·0	·00391
10	140·	3·55	19600·	415·0	59·29	16·87	0·5274	1896·2	·00889
⅛ 11	125·	3·17	15625·	330·9	47·27	21·16	0·6615	1511·6	·01400
	120·	3·05	14400·	304·9	53·56	23·28	0·7178	1393·1	·01648
12	110·	2·79	12100·	256·2	36·69	27·32	0·8543	1170·6	·02334
	100·	2·54	10000·	211·8	30·91	33·06	1·0336	967·5	·03417
13	95·	2·41	9025·	191·6	27·30	36·63	1·1453	873·1	·04195
14	85·	2·15	7225·	153·0	21·12	46·28	1·4472	691·0	·06698
15	75·	1·92	5625·	119·1	17·02	58·77	1·8376	544·2	·10799
	70·	1·778	4900·	103·76	14·82	67·46	2·1095	475·1	·14241
16	65·	1·651	4225·	89·47	12·78	78·24	2·4465	408·8	·19141
1/16	62·5	1·587	3906·	82·72	11·82	84·62	2·6462	386·7	·22392
	60·	1·521	3600·	76·23	10·89	91·82	2·8712	348·3	·26370
17	57·	1·440	3249·	68·80	9·83	101·75	3·1814	314·3	·32369
18	50·	1·274	2500·	52·94	7·563	132·22	4·1346	241·9	·54669
19	45·	1·143	2025·	42·88	6·126	163·25	5·0927	196·0	·83324
	43·	1·092	1849·	39·16	5·593	178·78	5·590	178·9	·99910
	42·	1·066	1764·	37·36	5·236	187·39	5·8597	170·7	1·0981
20	40·	1·016	1600·	33·88	4·840	206·60	6·4603	154·8	1·3347

millimetre	39·37	1·	1550·	32·823	4·689	213·26	6·669	151·0	1·429
21	35·	·889	1225·	25·941	3·705	269·84	8·438	118·5	2·278
22	32·	·813	1024·	21·684	3·101	322·81	10·094	99·1	3·259
	30·	·762	900·	19·059	2·729	367·29	11·485	87·1	4·218
23	28·	·711	784·	16·602	2·371	421·63	13·184	75·9	5·559
24	25·	·635	625·	13·235	1·891	528·90	16·539	60·5	8·747
25	23·	·584	529·	11·202	1·604	624·88	19·540	51·2	12·210
26	19·	·483	361·	7·648	1·092	915·78	28·633	34·9	26·219
27	18·	·457	324·	6·845	·991	1020·3	31·902	31·4	32·549
28	16·	·406	256·	5·421	·774	1291·3	40·377	24·8	52·137
29	15·	·381	225·	4·765	·681	1469·1	45·940	21·8	67·493
metre-gramme	14·9	·379	222·13	4·704	·672	1488·1	46·534	21·5	69·250
30	14·	·355	196·	4·151	·593	1690·4	52·727	19·0	88·943
31	12·	·305	144·	3·049	·435	2295·6	71·780	13·9	164·78
32	10·	·254	100·	2·118	·303	3305·6	103·36	9·7	341·68
34	9·6	·244	92·16	1·952	·279	3586·8	112·16	8·9	402·29
	9·	·228	81·	1·715	·246	4081·0	127·90	7·8	520·78
35	8·7	·221	75·69	1·603	·229	4367·3	136·56	7·3	596·41
	8·	·203	64·	1·355	·194	5165·0	161·51	6·2	834·19
36	7·9	·200	62·41	1·322	·189	5296·6	165·62	6·0	877·23
Foot-grain	**6·872**	**1·75**	**47·22**	**1·**	**·14286**	**7000·**	**218·89**	**4·5684**	**1532·2**
37	6·7	·170	44·89	·951	·136	7363·7	230·26	4·3	1695·6
38	5·8	·147	33·64	·712	·102	9826·4	307·27	3·3	3019·3
	5·5	·139	30·25	·641	·092	10902·	341·70	2·9	3734·0
	5·	·127	25·	·529	·0756	13222·	413·46	2·42	5466·9
39	4·2	·106	17·64	·374	·0534	18739·	585·97	1·71	10981·
	4·	·106	16·	·339	·0484	20660·	646·03	1·55	13347·
40	3·9	·099	15·21	·322	·0460	21732·	679·58	1·47	14769·
41	3·3	·084	10·89	·231	·0329	30354·	949·17	1·05	28812·
Mil.	**1·**	**·0254**	**1·**	**·0211761**	**·0030252**	**330560·**	**10336·5**	**·0967447**	**3416825·**

(1) Both pairs of wires joined in the middle, so that the current returns on itself and prevents induction; the two exactly balanced.

(2) Both coils with the current going through; exactly balanced.

(3) The coils arranged one in each way, so that there is induction in one and not in the other; now here is work absorbed, for a current is generated at making and breaking contact and a spark produced, and this "extra" current is either created out of nothing, or it is derived from the battery indirectly; if the latter, it is extra work; and therefore resistance increases, and will at once show on the balance, § 216. It does so—the needle, under the present conditions, swings 5° on one side at the instant of contact, when induction occurs, returns to the zero when this first effort is over, and on breaking contact swings 3° the other way.

(4) Both coils being arranged as in experiment 2, they balance. I insert a piece of iron in one; the effort to magnetize this is a heavier exertion, and the needle swings 12° to the side of whichever coil contains the iron, and remains permanently at 3°.

(5) I give the magnet work by adding a piece of iron for it to support. The needle flies over 5°.

Of course all this is well known, but I detail the experiment to put it plainly before those who do not know it. I do not give the measures of the resistance, as it is very small; the magnet, under these circumstances barely supporting an ounce, as the object was not to obtain a powerful magnet, but to effect various changes in the conditions. But it brings out very forcibly a fact of much importance. Having once arrived at the principle that the resistance increases as work is put on a circuit, then we see that the proportion this extra resistance bears to the total is the measure of that portion of the expended force converted into useful work; the resistance of the very best electro-magnet under these conditions while working is very little increased in proportion to the resistance of the circuit when it is not working. Therefore work done by electro-magnets must be very costly, because the source of our force is so, and we can utilize only this small proportion of it as work.

A most interesting experiment by Favre gives the quantitative relations very clearly. Testing the heat developed in varying circumstances, he found that the heat developed in a whole circuit, doing no work, was exactly the same as that given by the same weight of zinc dissolved without producing any current. Following this out, he tested the heat in various conditions of circuit, and also when a known amount of work was done by a magnet, the work being the equivalent of 308 heat-units or calories.

The conditions of the experiments were for the same weight of zinc.

(1) The battery on short circuit; heat all developed in the battery itself.

(2) The circuit going through an electromagnetic coil without the iron, as in my experiment 3.

(3) The same with the iron inserted.

(4) The magnet revolving a machine, but doing no work.

(5) The same, but doing work.

Expt.	Heat in Battery.	Heat in Circuit.	Heat lost as work.	Total Amounts.
1.	18682	—	—	18682
2.	18674	—	—	18674
3.	16444	2219	—	18667
4.	13888	4769	—	18657
5.	15427	2947	308	18682

The experiment shows very clearly the relations of force to the effect produced; and also the mode in which resistance converts the force into work, and it closely agrees with the details of my experiment above.

232. RESISTANCE OF LIQUIDS.—For equal dimensions this is vastly greater than that of metals, but it is subject to the same laws; it varies inversely as the sectional area, and directly as the length. Therefore, by doubling the area, or what is frequently the same thing, doubling the size of the plates, we halve the resistance, or may double the distance apart without increasing the resistance. This holds exactly true only when the plate fills a cell of square section, as to which see § 233. The law also holds true only as to the real liquid resistance, the molecular motion in the liquids themselves. There are really three elements of resistance in most liquids:

(1) The true liquid resistance just spoken of, and to which alone this section refers.

(2) The resistance at contact of the plate and liquid which varies the active area, as when a gas is given off and covers part of the surface: this may be regarded as analogous to dirty surfaces or bad soldering with wires, &c.

(3) An absorption of energy when an electrolyte is decomposed, which has been given the confusing name of "polarization" of plates, as to which see § 290.

The resistance of a porous cell is really due to the reduction of the area of the liquid: hence, if this be measured in ohms, it will be different if the liquid is a good or bad conductor, as its resistance is really that of the quantity of the liquid it displaces and does not absorb.

Heat has the opposite effect in liquids to that upon metals: for heating *diminishes* the resistance. In some cases the resistance at 32° is three or four times as great as at 212°, but very little is known on the subject.

Many philosophers have examined the facts of liquid resistance, but our information is by no means large or reliable.

The following table is calculated from experiments by Becquerel:

TABLE XII.—LIQUID RESISTANCES.

	Temperature.	
Copper taken as standard	32°	1
Sulphate of copper, saturated	48	16,855,520
„ „ diluted to half	„	26,327,637
„ zinc, saturated	56	15,861,267
„ „ diluted to half	„	12,835,836
Chloride of sodium, saturated	„	2,903,538
„ „ diluted to half	„	3,965,421
Sulphuric acid, diluted 1 to 11	68	1,032,020
Nitric acid, strength not given	—	976,000
Distilled water	59	6,754,208,000

He also gives the following particulars expressed in terms of conductivity. Pure silver being taken as 100,000,000:

	Temperature.	
Sulphate of copper, saturated	50°	5·42
„ „ diluted to half	„	3·47
„ „ „ to quarter	„	2·08
„ zinc, saturated	55	9·00
„ „ diluted to half	„	17·70
„ „ „ to quarter	„	13·44
Chloride of sodium, saturated	56	31·52
„ „ diluted to half	„	23·08
„ „ „ to quarter	„	13·58
Oil of vitriol 1, measure to 11 water	66	88·68
Nitric acid, commercial, 1·31 sp. gr.	56	93·77

It appears that in some cases saturated solutions are the best conductors; in others there is a particular degree of saturation at which resistance is least, conductivity diminishing both above and below it; these latter are deliquescent or extremely soluble salts; probably this may throw light upon the nature of solution and upon the question whether crystalline bodies dissolve as such, with their water forming part of the dissolved molecules, or whether only the salt itself is dissolved; many chemical facts tend to show that salts which crystallize in two or more forms with different amounts of water, have different solubilities in the different forms.

233. CONDUCTION THROUGH LIQUIDS.—It might be supposed that electricity takes only the shortest and straightest path, and that in a liquid with two plates in it, the current would be confined to the stratum of liquid lying between the plates. This is not the case. Electricity divides itself through every path open to it in the ratio of the resistances of each path. Therefore if small plates are immersed in a large vessel, every particle of liquid in the vessel will form itself into a path for current. This may be tested by means of two wires fixed into a frame and connected to a galvanometer; on dipping these into a liquid through which current is passing they will form part of the circuit, replacing the liquid lying between them, although they have no metallic connection to the plates or battery; according to the part of the liquid they are placed in will be the amount of current they intercept, and by calculation of the various elements of the current, this will show the relative quantities of electricity passing in different parts of the vessel.

FIG. 63.

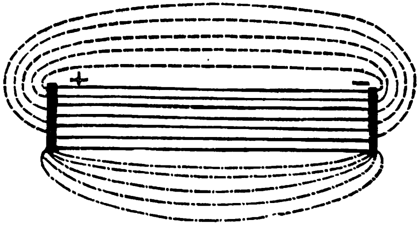

Fig. 63 shows the facts: even the backs of the plates take part in the action, and it is most active upon the edges from the same causes which render points and edges active in static electricity, § 50. Hence, contrary to common opinion, the backs of battery plates are to some extent active. Mount a pair of plates with one side varnished, either as a battery or in a coppering cell with a galvanometer, and note the effect when the varnished sides or the bare sides are presented to each other.

234. EARTH CONNECTION.—These facts explain why the resistance of a telegraphic return circuit by earth plates is so small as to count for nothing as compared with that of the wire. The return current passes through the liquids of the earth and sea just as in the case of a common decomposition cell, and its plates are subject to the same effects of polarization, § 290, but the lines of current are not

limited, they spread out in all directions, as in Fig. 63, and the result is that the only actual resistance is of the order 2 and 3, § 232. There is another theory favoured chiefly by mathematicians, that the earth may be regarded as an infinite reservoir, § 25, or else as an infinite pair of condensing plates in which the tensions set up in the wire are lost.

But if we enclose a liquid or moist earth in a tube we find that tube is a conductor, and it acts in all respects as a wire does; we may lengthen it or add tube to tube, still the same, still the resistance as it grows obeys the definite laws: why then set up a new idea when we deal with the earth? this is we know a mass of electrolytes, and we know also that the plates act exactly as two plates in a solution do. The analogy has another view: if we use a copper earth plate in London and a zinc earth plate at a distance and in such a direction as eliminates the disturbing action of the natural currents of the earth, these plates act precisely as though they were in a cell, they produce a current traversing the wire, and if we soak the earth around the copper plate with a copper salt, we get all the effects of a Daniell cell: is it not obvious then that the intermediate earth is acting precisely as does the liquid in an ordinary cell and completing the circle of the current?

235. The following description is that of an instrument devised for measuring the true electric resistances of liquids and eliminating all disturbances. It is really a Wheatstone's bridge, or may be used with a differential galvanometer. Three glass cells are connected together by two tubes of different lengths and mounted upon a stand, with connecting screws close to them provided with a vertical hole. These are for the plates or conductors attached to a wire which can be easily put in position. A resistance coil is placed in the circuit of the shorter tube so that the current which enters at the middle cell and divides through the two tubes may be equalized, thus causing exactly the same polarization effects in both branches: if we regard the middle cell as – and the two tubes as the arms A C in Fig. 58, the action is evident: the extra resistance of the coils is exactly equal to that of the extra length of the longer tube. In order to obtain definite measures, the instrument is first charged with mercury and thus a standard of comparison is obtained which dispenses with any accurate measures of the tubes or liquids, for the liquids are really compared with an equal bulk of mercury under exactly the same conditions, and these conditions equivalent to a known standard resistance. Open oblong cells may be used in place of tubes, provided that the plates completely fill the cross section; in this case the two sides of the middle plate distribute the two currents.

236. **Resistance, Definition of.**—Before leaving the subject a

résumé of the foregoing facts and principles will furnish a clear definition of the nature of resistance. It is the expression and measure of the amount of energy necessary to be expended in order to produce a certain effect, which we may call the transmission of a definite "electric quantity" (not quantity of electricity, see § 186). The molecular movements produced by this action in a wire, &c., consume energy and produce heat, and the quantity of the energy and heat necessary in a unit quantity of the substance is the equivalent of its *specific* resistance, § 221.

Resistance takes many forms, and any action or force which necessitates energy to overcome it may be treated and measured as a resistance, but *true resistance*, that is, "specific resistance," being an absolute property of each substance or definitely related to each form of work, is invariable, i. e. it bears the same relation to the force exerted upon it, be that force or the electric current produced by it, great or small. It is thus with the resistance of wires (allowing that is for the effect of temperature, § 229). The formula $\frac{E}{C} = R$ will give for R the same value, whatever the actual dimensions of E, when it and R C are measured in systematic units.

A Counter Electromotive Force, § 289, may be measured as a resistance in the bridge or differential galvanometer so as to balance it by an extra length of wire, but that *length will not be constant*, it will hold a varying relation to the current passing: it is therefore not a true resistance; express it properly as $\frac{E - e}{C} = R$ and then a constant result is obtained.

Work, which sets up no counter force, may be measured as resistance, and this will give the energy consumed in effecting the work, § 231. By first measuring the resistance without the work, and then while the work is doing (with the same current passing), we have in the extra resistance the measure of the work independent of the electromotive force engaged or the actual current passing, these being of course related to the total resistance, including the work of the whole circuit. $W = C^2R$ is the formula, which requires also a constant representing the mechanical equivalent of C in the system of measurement employed. This is the same formula as that for heat, § 191.

237. CONSECUTIVE RESISTANCES.—Each portion of the circuit, i. e. the various cells of the battery, the connecting wires, any instruments used or work done, having each their separate resistance measured or known, these are all added together to form the total resistance of the circuit, symbolized as R: it is this total resistance only which can be calculated directly by Ohm's formula,

but the various external resistances may be ascertained separately by that formula by observing the variations of the current produced as each is added. For the Internal Resistance of the Cells see § 271.

238. **Derived Circuits**, see § 214.—When the current divides into two or more branches for a part of its course, the joint resistance of the united circuit is ascertained by the following formulæ; the separate resistances being first ascertained by the usual processes:—

(1) $\frac{A \times B}{A + B} = R$. The joint resistance is the product of the two resistances divided by their sum. Thus

$$\frac{\cdot39 \times \cdot64}{\cdot39 + \cdot64} = \frac{\cdot2496}{1\cdot03} = \cdot242.$$

When there are more than two paths, having obtained the joint resistance of two, this is used with another in the same manner. Let C be another such path having a resistance 1·9, then

$$\frac{\cdot242 \times 1\cdot9}{\cdot242 + 1\cdot9} = \frac{\cdot4598}{2\cdot142} = \cdot215.$$

(2) It is more easy to obtain the joint resistance by means of a table of reciprocals: the sum of the reciprocals of the separate resistances being the reciprocal of the joint resistance. (The reciprocal of a number is 1 divided by it; tables of reciprocals are given in many books.)

A = ·39	reciprocal	2·564
B = ·64	„	1·562.
C = 1·9	„	0·526
Joint resistance	.. ..	4·652 = ·214.

(3) Another plan may be derived from the system of wire resistance, § 227. If we reduce each resistance to the terms of the area of a copper wire of fixed length 1, 10 or more feet, the sum of these represents a wire equivalent to the joint resistance.

239. **Cells in Multiple Arc**, or as it used to be called, coupled for quantity, that is to say, side by side, so as to act as one larger cell, are derived circuits; the current divides itself between them; their resistances obey the same law as that of the outer circuit, and the joint effect is found by the same formulæ. The examples used, § 238, are in fact the internal resistances of the cells used in § 243 to explain the laws of current.

Cells to be coupled in multiple arc may be of various sizes, but must be all of the same kind and of equal electromotive force, otherwise the stronger cells reverse the current of the weaker and less current passes to the external circuit than if the weaker cell were not used, and yet the stronger cell is more rapidly exhausted: zinc may also be deposited on the negative plate of the weaker cell, if it is a single liquid cell. So also when a number of cells are arranged in sets in series, and then coupled in multiple arc, all of the sets in one coupling must contain the same number of cells in order that when in multiple arc each branch may have the same electromotive force. In this manner a variety of cells of different sizes and forces may yet all be used in one circuit, and combined in both ways, for small resistance (multiple arc) and high electromotive force (in series).

CHAPTER VII.

CURRENT.

240. **Quantity and Intensity.**—Our greatest poet has told us that a rose by any other name would smell as sweet, and this phrase is often used as signifying the unimportance of mere words. In science, however, it is impossible to exaggerate the importance of words, because words stand for things and principles, and the great stumbling-block in the way of scientific students is the indefiniteness of the terms commonly used, and in no science is this more serious than in electricity, many of the terms of which have had a succession of different ideas attached to them by different writers, thus generating a confusion from which we must fully extricate ourselves if any sound knowledge is to be attained. In § 71 is given an explanation of the relations of "quantity" to surface, and why the force associated with it increases as the square of the quantity. We have to deal with the same principles in current electricity, and the reasons why the energy, work, heat, &c., of currents vary in the ratio of the squares of the currents will be found § 279.

In the early days of current electricity the battery was regarded as something in the nature of a pump, which would supply a quantity of electricity proportioned to its size, and the circuit was regarded as something like a pipe, which required simply to be large enough to allow that "quantity" to run off; the larger the pipe the more it would carry away from the positive pole of the battery, which might be regarded as the spout of the pump, and intensity was needed in the battery in order to carry the flow to a greater distance, that is to say, through longer wires.

These ideas still linger in the minds of those who have not studied electricity scientifically; but they are entirely erroneous, based on misconception, and have been entirely superseded by the formulæ of universal application, known as Ohm's laws. But here, again, there is a misconception. Ohm's work was a great one—his formulæ most valuable; but they are nothing new, for if examined they will be found to be simply the common fundamental mechanical laws, and the relations established by Ohm's laws between electromotive force, resistance, and the current and its work, are simply the well-known laws of mechanics or the relations between force, such as gravity, weight, and velocity.

But, further, these laws of Ohm are merely mathematical expressions: invaluable in dealing with the modes of operation, they only delude us if we regard them as facts, and do not clearly trace out the reason why they are valuable. Indeed, the devotion of practical electricians to Ohm's laws often leads them into errors just as great, though in an opposite direction, as those which these laws have freed us from; thus to obtain anything like a clear conception of the electric current, its modes of action, and its work, it is equally important to disabuse the mind of all the old ideas of quantity and intensity, and to guard against being utterly enslaved by mathematical chains. In point of fact, there is in the galvanic current neither quantity nor intensity, or if we use those words we must give to them entirely new meanings, detaching them entirely from any relation to the supposed fluid electricity. Thus, *quantity* can only mean a definite chemical action—a certain number of molecular changes, each of which has a definite chemical result, and is also attended with a definite magnetic result, magnetism being simply a polar arrangement of molecules, and, therefore, having naturally a fixed connection with the molecular chemical changes. These changes are perfectly expressed as to their quantitative effects by Ohm's laws, when we connect to these laws the known relations of chemical equivalence.

The ordinary idea of *intensity*, as produced by a number of cells, is still less fitted to the facts of the galvanic current, for we can obtain exactly the same effects from currents of equal quantity, whether they arise from one cell or from fifty. Ohm's laws fully express this, but they tend to lead the mind to suppose that there is no real difference in these currents. They tend, as generally used, to drive out altogether the idea of intensity, which, properly understood, is equally important with that of quantity, for although in some aspects, the two supposed equal currents would be alike—as to magnetic actions and as to quantity of chemical action, they would really be also very different, and regarding the difference as solely due to the balancing of electromotive force and resistance in the abstract, without weighing the sources of force and nature of resistance, is sure to end in overlooking important features of the subject.

241. OHM'S LAWS.—It will be more convenient to show how these formulæ explain the facts of the galvanic current before discussing the sources of the force they are based on. The fundamental expression is $C = \frac{E}{R}$ or $\frac{\text{force}}{\text{resistance}}$ = current, or work

done in given time. If the data are comparative, the results are so also; but using definite units, we get the result in actual units also, as explained § 202. In the simple equation the symbols represent the total of each element. Thus supposing we have more cells than one, say four, the equation is $\frac{4\,E}{4\,R} = 1\,C$, which shows us that on short circuit, or when there is little resistance except that of the battery itself, a number of cells in series give no larger current than a single one, because each one adds its own force and its own resistance, and if they are all alike the result is unchanged. If cells of different force are connected in series their forces are added together to give E. Thus the force of Daniell's cell is in volts, 1·079; Grove's, about 1·964; hence, for these two cells in series, E would be 3·043. The resistance, also, is compound, being the sum of that of all the internal resistances of the cells, of the connections, and of any circuit or work doing. These details are generally enlarged into elaborate formulæ, but it is better to keep in view the simple formula as representing the total, however composed, of each element in calculations; the details will be better understood under other headings.

It follows that any two of the three elements, E, R, and C, being known, we can calculate the third thus:

Current. $\frac{E}{R} = C$. Force and resistance being known.

Electromotive Force. $C \times R = E$. Current and resistance being known.

Resistance. $\frac{E}{C} = R$. Thus, with any cells the force of which is known (as most are) in volts, dividing this by the current in vebers, gives us the total resistance; and if the external resistance is known, by deducting this we get the internal resistance of the battery.

242. The Veber.—By various experiments it has been ascertained that the British Association unit of current, § 207, is capable of doing the chemical work per second stated below, and thus its value can now be ascertained in the practical unit of current used in these pages, the Chemic, § 110, p. 86.

1 veber per second	× 36000	÷ equiv.	=	Chemics.
·00142 grains water	51·12	9	=	5·680
·00158 „ hydrogen	5·688	1	=	5·688
·00514 „ zinc	185·17	32·6	=	5·681

These values, given by Ferguson and Clark, show that the veber current is equal to 5·68 chemics during equal times, and so enable this practical and easily understood unit of current to work with Ohm's formula and the B. A. units.* On the other hand, by multiplying the electromotive force in volts by the same figure, 5·68, and reckoning resistance in ohms, Ohm's formulæ give the current in chemics. Thus the E M force of the Daniell is 1·079 volts. 1·079 × 5·68 = 6·1287. Then $\frac{1·079}{1·079}$ = 1 veber, or 5·68 chemics, which would read as 46·5° on the galvanometer dial (§ 179); so, also, $\frac{6·1287}{1·079} = 5·68$. This latter process is the most convenient for use with the chemic unit of current, as it only requires a few electromotive forces to be multiplied once for all.

243. Current.—The following table is a series of experiments arranged to show, at one view, how the formula $\frac{E}{R} = C$ explains every possible case. It is the working of three Daniell cells of different sizes under varying circumstances of arrangement and of external resistance. It will well repay the closest study, as it embraces every point on which information can be sought. The electromotive force is taken in values corresponding to the chemic current (§ 242), and the current is given in chemics as read direct from the galvanometer, Fig. 49, p. 132.

Lines 1, 2, 3 show the action of each cell by itself, on short circuit and with varying resistances.

Lines 4–7 cells in series, or, as it is often called, combined "for intensity."

Lines 8–11 cells in multiple arc or coupled for quantity (§ 239).

Column I.—Gives the cells as used in each experiment.

II.—The electromotive force, due to the mode in which they are combined, increasing in the ratio of the number in series, without reference to size.

III.—The internal resistance of the cells, as combined, the mode of calculating which is given, §§ 237–8.

IV.—External resistance on short circuit, being that of the conductors and galvanometer.

III. and IV. together are the total resistance, R, on short circuit.

V.—The currents observed on short circuit.

VI.—The same; values calculated by the formula $\frac{E}{R} = C$, being Columns $\frac{\text{II.}}{\text{III.} + \text{IV.}}$ = VI. It will be seen that these closely agree with those observed in Col. V.

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* The last Column of Table XIII. gives the chemical equivalent of the veber of the most important elements.

VII. and VIII.—Correspond to the foregoing, an extra resistance of two ohms being added.

IX.—Is calculated for a still further addition of 10 ohms to the external resistance.

It will be seen that although the observed and calculated figures agree so closely as to prove the truth of the principles involved, yet there is not exact agreement. There are in all experiments some sources of error; instruments are seldom perfectly exact, and very trifling errors in graduating the galvanometer will tell; besides, it is not easy to read off with great exactitude on a circle of three inches diameter, and by the eye. The internal resistance, also, varies during a set of experiments, owing to the action on the zinc and many other causes, and the figures taken are the average of several results, used throughout for convenience.

Connection of Cells.

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
Cells.	Electromotive Force. E.	Intl. Resistance. R.	Extl. Resistance. r.	C=Current in Chemics.		C=Current in Chemics.		With 10 Ohms added to VII.
				Observed.	Calculated.	Observed.	Calculated.	
1. A	6·129	·390	·11	12·49	12·37	2·52	2·46	·490
2. B	„	·64	·11	8·19	8·21	2·23	2·23	·481
3. C	„	1·90	·11	2·97	3·05	1·42	1·53	·437
In series								
4. A + B	12·257	1·030	·11	10·99	10·75	3·99	3·91	·933
5. A + C	„	1·99	·11	5·89	5·86	2·84	2·98	·869
6. B + C	„	2·54	·11	4·76	4·62	2·55	2·63	·836
7. A, B, C	18·386	2·93	·12	6·20	6·04	3·74	3·65	1·222
Parallel.								
8. A & B	6·129	·242	·11	17·70	17·41	2·46	2·60	·497
9. A & C	„	·324	·11	14·36	14·12	2·42	2·42	·493
10. B & C	„	·479	·11	10·88	10·41	2·34	2·37	·487
11. A, B, C	„	·214	·12	18·82	18·35	2·71	2·63	·498

244. Size of Cell.—The table shows at once that with one electromotive force, that is, a cell of any battery, the current is proportional to the total resistance, for when this is only that of the battery itself, then the current is proportional to that, i.e. on short circuit, the current is proportionate to the size of plates, &c., rising steadily through lines 3, 2, 1, 10, 9, 8, 11, as the size of cell increases.

On the other hand, if the external resistance is large, there is no use in increased size of cell, for Col. VII. shows an approximation in the figures on these lines; and in Col. IX., where the resistance is large, the lines are all practically alike, and the little cell, with two square inches of plates, gives a current nearly equal to all the cells together.

245. COUPLING CELLS.—Against small external resistance there is no advantage in coupling in series, for in lines 1 and 2 we find the cells alone give a current of 20·5, while in parallel connection, line 8, they give 17·7; but line 4, in series, they give only 10·99. This further illustrates the mischief done by inserting a smaller cell in a series, for two like A would give a current of 13·74, a little more than one, but at double cost.

Against large external resistance we gain by series, as we see in lines 1, 2, compared with 4 in Col. VIII.; and in Col. IX., where the resistance is considerable, lines 1, 4, 7 show a proportion of current closely in the order of the series of cells.

246. EXTERNAL AND INTERNAL RESISTANCE.—The foregoing observations are really included in the common statement that to get the maximum of work combined with the minimum of cost, the external resistance must equal the internal; in other words, the size of plates and number in series must be adjusted to the amount of work required to be done, and the resistance to be overcome. But this must be considered intelligently; assuming external resistance to be greatest, we may increase internal resistance in several ways. 1. By increasing series—this is to be done if we wish to increase the current, because we also add to the force. 2. We may reduce the size of the plates, i. e. use small cells, and get as good work as with large ones. 3. We may use solution of salt, or even water and other bad conductors, and thus diminish the local action; both these plans are useful where we have sufficient current from the series, and the second is of first importance in selecting cells for any given work.

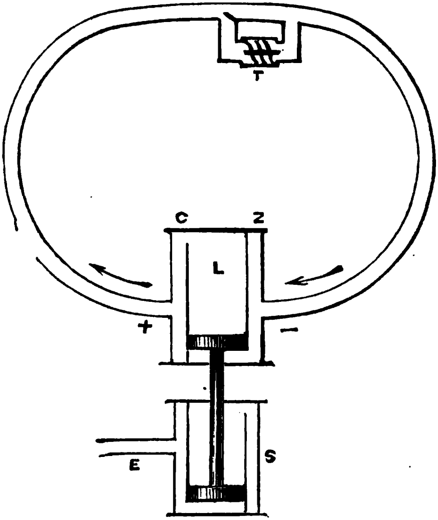
But increasing internal resistance is not to be effected by aimless means, such as inserting unnecessary porous diaphragms, or merely increasing the distance of plates, for these would increase cost, as it must be remembered that the materials are expended on the resistance, of which only the external is really utilized in either working or carrying the force to its work. Therefore, by increasing external resistance in proportion to internal, we can diminish the cost of a given "quantity" of work, but we increase the time required, i. e. we diminish current; in other cases we may do the same with greater economy by reducing the internal resistance, as by diminishing the number of cells in series.

247. CURRENT AND ITS RELATIONS.—There have been many attempts to explain the actions of the galvanic current by mechanical analogies, and as such analogies certainly may convey ideas to the minds of many more fully than formulæ do, I will

attempt one. Such analogies are never perfect, and always fail at some point, yet there is a very strong parallel to be found between the conditions of the closed circuit of a battery and a set of hydraulic machinery.

Fig. 64 represents both subjects.

FIG. 64.



L is the pump actuated by the steam cylinder, S; C being the outlet, and Z the inlet; these are connected by a continuous pipe provided with the means of connecting T, a turbine or cylinder, which may be made to do work by the pressure developed at the pump.

L is also the galvanic cell, of which C and Z are the plates, and the pipe becomes a wire transmitting the current from + to –, or in the same directions as the arrows marking the flow of water. T is an electro-magnet, or decomposition cell, or any apparatus in which work is to be done.

To carry out the analogy we must conceive E to be a steam pipe, conveying steam of, say, 10 lb. pressure, at such a rate as to fill the cylinder, and, therefore, work the pump sixty strokes per minute when T is disconnected.

E now exactly represents the electromotive force of the cell; each filling of the steam cylinder one equivalent of chemical action on the zinc; each filling of L one equivalent of mechanical or electrical action. The two ideas are now exactly parallel; for each stroke of the mechanical action, fast or slow, a fixed *quantity*, or current of water flows through the pipe, and the same quantity will pass, in the same time, across every section of the circuit; so for each unit of Z dissolved, a current equivalent to one unit will flow through the wire, whether the zinc be dissolved quickly or slowly, and there is exactly the same "current" or quantity in given time at every section of the circuit.

Now let T be placed in the circuit and made to do work. This is increased resistance. The strokes of the pump—the consumption of zinc—therefore, the *current* in either case will diminish. Exactly the same laws, precisely the same formulæ, will govern the rate of decrease, mechanical or electrical.

When a certain point of diminution is attained—i. e. a certain resistance interposed at T, the pump or battery will be overpowered, and to do work we must increase the electromotive force or the steam pressure.

In both cases we see the current is uniform at every part of the circuit, and also it would be exactly equal in measure, estimated by gallons of water, and by galvanometer degrees, whether 60 strokes per minute were made by 10 lb. steam, or one equivalent of action effected against small resistance, i. e. on short circuit, or whether T was doing work so great as to require 100 lb. steam pressure—or 10 cells of the battery to maintain the rate of current flow.

But would the mechanical or electrical conditions be all the same; would the two currents—equal in quantity—be alike in all their properties? Most certainly not.

If we applied pressure gauges to the pipe on the + side, we should find a *pressure* diminishing as we reached the middle; on the – side we should find a *vacuum*, or – pressure, and we should find the sum of these two, at equal distances from the pump, would represent the mechanical force available between them, which would be equal also to the friction or other resistance in the intervening space. Thus, two pressure gauges, at the inlet and outlet of T, would vary according to the amount of work T was doing, and when this was so great as to need 100 lb. steam to maintain the 60 strokes per minute, a gauge at + outlet would show ten times the pressure it would when 10 lb. sufficed, though exactly the same "quantity" of water passed in both cases.

Difference of pressure, then, or sum of + and –, pressure and vacuum, is the measure of work in the hydraulic current, or resistance intervening. It is exactly the same with the galvanic current; and what I have been aiming at is to connect in my readers' minds the idea of mechanical *pressure* and electric *tension*, for to this latter is applicable every remark made as to the former, § 215.

When plates of zinc and another metal are immersed in acid, there is no apparent effect; but suitable apparatus will show that there is an appreciable effect produced, for a condenser may be charged to a degree of tension differing according to the negative metal employed (if this condenser be large enough, the time necessary to charge it will be so prolonged as to enable a galvanometer to show that a measurable current is set up, although there is no circuit of conducting materials). If we connect the condenser to a battery of ten cells, there will be a tension developed ten times as great as though one cell were used.

If the circuit be closed by a wire along which current is passed, still a condenser may be charged by connecting as a *derived circuit;* although one branch is a *conductive* and the other an *inductive* circuit, and the actual resistance of the last is almost immeasurably greater than the other, yet the condenser will take a charge equal to the tensions which, by the laws of the *conductive* circuit, exist at the points of connection, § 215, Fig. 55.

Electric tension then is the analogue of mechanical pressure or strain, and we may compare the electric circuit and the molecules of which it consists to a series of spiral springs, Fig. 40, p. 85; and in each case energy is stored up and partly consumed in setting up strains, which in their turn give up and transmit the energy.

CHAPTER VIII.

ELECTROMOTIVE FORCE.

248. **Energy and Matter.**—Some of the general relations of force to matter have been examined, §§ 13, 104–10, 196–7; we have now to examine more closely how force assumes the form of electric energy or electromotive force. For this purpose we must remember that each atom and also each molecule of matter involves as part of its inherent nature an amount of energy as definite as of matter, but unlike the matter, not permanent in all changes; it is definite and fixed only for a definite and fixed condition, and for every change a definite change takes place in the amount of fixed energy. We must, therefore, regard force as possessing twofold conditions.

(1) Fluctuating, such as the sensible heat of substances, which enters and leaves them according as they are surrounded by bodies of greater or less temperature, but which does not change either their physical state or chemical properties.

(2) Fixed, linked inextricably with the matter. This is what used to be called *latent heat*, now termed, particularly by mathematicians, *potential energy;* but the best and most definite idea will be obtained of it by treating it, as an amount of force linked to, or charged upon, the atoms and molecules of matter, and inseparable from them without change of nature or physical state, the mode of charging being the imparting of internal motion. Every elementary atom has its special force, and the importance of this view will be seen when we find that the degree of this force is really the measure and the cause of the chemical force or *affinities* of this atom. Each substance also requires a definite amount of force to pass from one physical state to a higher, as from solid to liquid and gaseous; at each such change a definite amount of force disappears, becomes charged on the molecules, i. e. is converted into latent heat or potential energy. So also, every chemical action which occurs under the influence of affinity, that is every act of *combination*, is attended with a loss of force, i. e. the potential energy is set free, and becomes active and sensible in some form, either as heat, or electricity, or motion. On the other hand, every act of decomposition (the reversal of affinity) requires a supply of force exactly equal in quantity to that set free by the act of combination, and this force

is again charged upon the atoms or molecules, and disappears—without it the change cannot occur.

To make all this really clear, and to attach to our chemical symbols their value in force as well as matter is at present impossible, as the data are not yet sufficiently ascertained, notwithstanding the labours of Favre and Silbermann, Andrews, and more recently of Thomsen and Berthollet. Most of the earlier of their results are given in relation to grammes or pounds in weight, and require translation into the comprehensible relations of the atoms; of late, however, results are almost always so stated, indicating a great advance towards a clearer understanding of the real scientific road. But they are always given in the metrical system, and as the general English reader would not realize the meanings, I have reduced the information to the units used in these pages, the equivalent in grains weight for matter, and the foot pound for energy, § 105.

249. Relations of Units.—It must be understood that the figures given are only approximately correct. They are mainly the results of experiments subject to many causes of error; it is also most difficult to know what value to give to the figures because weights and units are by some taken at 0° cent., the freezing point; by some at 4° the point of greatest density of water; and by some at 60° Fahrenheit. Hence different good authorities call the gramme equal to grains, 15·438, 15·434, 15·43235, and the gramme degree or calory has different values according to whether it means from 0° to 1° or from 4° to 5°; hence different authorities give different figures. I have therefore taken certain figures as the basis of calculation, and they will be found in Table XVII., § 257, with their logarithms, by means of which any values met with in books can be converted into any other system desired. The whole are based upon the gramme as 15·434 grains, and the calory as 423·55 gramme-metres, and therefore can be easily corrected to any other values deemed more correct. The mode in which the figures are obtained, and the plan of using them, will be best seen in an example. Andrews gives the heat of combustion of zinc in oxygen as—

			Log.
Calories per gramme ..		1330	3·1238516
Equivalent of zinc		32·6	1·5132176
Calories per gramme equivalent			4·6370692 = 43358
Ratio of grain equivalent. Table XVII., line 9		·198547	$\bar{1}$·2977983
Foot pounds per grain equivalent			3·9348675 = 8607·5
1 lb.	7000 ..	3·8450980	
Zinc	32·6 ..	1·5132176	2·3318804
Foot pounds per pound			6·2667479 = 1,848,195

Owing to the various differences this latter value is sometimes given as low as 1,463,925 per pound.

Any such differences or errors, however, will only affect the actual values; they will not prejudice the principles to be deduced from them, and they are so important that I have grudged no labour on my part to make them evident, and thus to give readers a clear view of subjects which to most minds are involved in obscurity.

250. SPECIFIC ENERGY.—The relations between matter and energy in form of heat (specific heat, § 196), and the resulting changes of physical state (latent heat, § 248), have no connection with the generation of electric energy except indirectly in some minor degrees, and principally as affecting resistance. The relation to be now studied is that of chemical actions.

The facts have been carefully studied by Andrews, Favre, and Silbermann, by Joule, Thomsen, and many others, mainly under the form of heat; Favre, however, our chief authority, has used electricity, not only as a check, but also as a basis of reasoning by which to anticipate experiment, and deduce laws and figures not readily obtained direct from experiments on heat. Therefore, though seeking to place these facts to some extent in a new light, I am offering no new theory, but merely trying to systematize and draw important lessons from facts and laws already established.

251. COMBUSTION.—The act of combustion or burning is a common instance of chemical combination, and at present we may consider it as simply combination, the union under the influence of chemical attraction of atoms of carbon, or hydrogen, &c., and atoms of oxygen. There really is also a decomposition of the molecules of these bodies, but that we are not now in a position to estimate. Now, as it is a fundamental maxim that we can create neither matter nor force, and as this action gives us an available free force in the form of heat—where does this force come from? Evidently from the atoms entering into union.

$C + O_2 = CO_2$ is the symbol of burning carbon, producing carbonic acid (or more properly anhydride), and $H_2 + O = H_2O$ hydrogen burning into water, but these symbols give us no information as to the source of the force. It is, however, evident that before combination there was some force present tending to cause union, which we may call affinity, and that when the union is effected, the resulting substance must have within it less combined energy than its components had before, because the act of union has set force free in the form of heat. This is usually treated as a mere incidental consequence of the affinity; however, it bears an exact ratio to the chemical force, and may be made to give meaning to the old diagrams of elective affinity; by fixing attention upon it, as the "specific energy," capable of exact estimation, instead of the vague "affinity," we shall better understand the facts. Thus, using the equivalent notation, the burning of carbon is

$$\left.\begin{array}{ccccc} C & + & O & = & CO \\ 6 & & 8 & & 14 \end{array}\right\} + 2946 \text{ foot-pounds.}$$

$$\left.\begin{array}{ccccc} C & + & O_2 & = & CO_2 \\ 6 & & 16 & & 22 \end{array}\right\} + 9624 \text{ foot-pounds.}$$

Here the energy set free by the act of combustion is expressed in foot-pounds; it is the "specific energy," the measure of the force which holds together the atoms composing carbonic oxide, CO, and carbonic acid, CO_2; not wholly so, however, as the great difference between the two figures is due to the fact that a large portion of the energy of the first atom of oxygen is rendered latent in converting the solid carbon into a gas. We cannot be sure that all of the four centres or valencies of carbon, § 6, have attached to them equal specific energy, or we might be able to calculate the force from that given by complete combustion, but in examining actions under the influence of electricity, light will be thrown on this.

252. SALTS.—Combustion or oxidation is only one step in chemical combination, for almost all the substances used in electricity are salts, this term really including acids. The older view of salts, Berzelius's electro-chemical theory, supposed the first step to be oxidization, forming substances which were either acids or bases, according as the element was placed in the electric order, and partly, also, according to the number of oxygen atoms combined, and these two bodies, preserving their original electric relations, combined to form salts. Although this theory is abandoned, it has still so far a real basis of truth, that the chemical attractions of the elements do in great degree correspond with this arrangement, which so far survives in the new chemistry that the old electro-negatives are still called chlorous or acid radicals, and electro-positives basylous radicals.

Chemical considerations, and especially the behaviour of acids and salts under the action of the galvanic current, led to the adoption of the binary theory, which treats them as composed direct of two radicals, of which the acid, or chlorous one, is a compound containing the whole of the oxygen, while the basyle is an element or a compound having properties analogous to those of elements. On this view the formulæ of sulphates are

$$\left.\begin{array}{l} H_2,SO_4 \\ Zn,SO_4 \\ K_2,SO_4 \end{array}\right\} \text{ instead of } \left\{\begin{array}{l} H_2O,SO_3 \\ ZnO,SO_3 \\ K_2O,SO_3 \end{array}\right.$$

The ordinary acid being a salt of hydrogen, which is simply displaced by the other atoms possessed of higher "specific energy." This theory accords thoroughly with all the facts of electrolysis, and is that to which belong all the formulæ used in these pages. The older view of salts has, however, a present use in calculating the specific energy of acids and salts.

Returning to the constitution of salts on the old theory: SO_3 four highly negative atoms unite to form a strong acid, sulphuric (now called sulphuric anhydride); hydrogen as H_2O forms a weak base—water; while ZnO forms a stronger, and potassium, K_2O, the strongest base. By combining again, $SO_3 + H_2O$ forms ordinary sulphuric acid, from which the stronger bases can displace the water, forming in turn SO_3ZnO, and SO_3,K_2O, sulphates of zinc and potassium.

253. **Elements and their Energy.**—I have put together in Table XIII. the principal elements employed in electricity, and the most important information as to them. Columns I., II., and III., are the names, symbols, and atomic weights on the new notation, § 12, now generally adopted; IV. the old chemical equivalent, which is also the weight taken in grains, to which Columns VII. and VIII. refer; V. is the valency, see § 6, p. 4; VI. shows the weight corresponding to one unit of electrical current, the chemic, varying in some instances where two classes of salts are formed; VII. is the energy of union with oxygen; and VIII. that with chlorine of the equivalent, in grains, Column IV. These two columns are the specific energies of these chemical combinations, § 250. In some cases two values are given; they are different results obtained by Andrews (the upper row) and by Favre: the same remark applies to the other similar tables. Column IX. is the electric equivalent in grammes of the veber, per second.

It is commonly stated, on the authority of Faraday's early experiments, that electricity, passing through several solutions, decomposes them in the *ratio of the several equivalents* (Column IV.). This is not the case; this idea of *the equivalent of electricity* is a delusion based upon the accidental nature of the experiments. The truth, which became manifest only as the modern chemical theories were developed, is shown in Column VI., which shows that the quantity of any element released depends not upon its equivalent merely, but upon the state of combination in which it exists, see § 109, that is to say, the valency of the radical it forms.

254. **Combination of Radicals.**—It is evident that whether we call the formula of zinc sulphate, for instance, ZnO,SO_3, or Zn,SO_4, we have the same number of atoms, and, let them have come together how they may, the ultimate result is the same. Now we can actually build up this molecule on the first formula; that is, we can dissolve the oxide of zinc in sulphuric acid, while we cannot form it on the second formula because SO_4, the sulphuric radical or oxy-sulphion, is not capable of separate, uncombined existence. We are thus able to get at the specific energy of the sulphates

indirectly, by first ascertaining the heat of oxidation, and then that of solution of the oxide in acid; we thus get the total force, but only approximately, as we cannot separate from the total the force due to change of physical state. Table XIV. gives the result in foot-pounds of the experiments of Andrews and Favre, arranged as in Table XIII.; the considerable differences indicate the difficulties of the process.

TABLE XIII.—ELEMENTS AND THEIR PROPERTIES.

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
Name.	Symbol.	Atomic weight.	Equivalent.	Valency.	Electric Equivalent.	Intrinsic Energy. Foot-pounds per Grain Equivalent.		Veber Equivalent in Grammes. $H^2O =$ ·00092.
		New.	Old.			Oxygen.	Chlorine.	
ALUMINUM ..	Al	27·5	13·7	3–6	9·17	..	..	·0009370
CARBON	C	12·	6·	4	..	2946 9624	as CO as CO_2	..
CHLORINE ..	Cl	35·5	35·5	1	35·5	..	..	·0036289
COPPER (*ic*) ..	Cu	63·5	31·75	2	31·75	3802 4345	6036 5861	·0032456
„ CUPREOUS	Cu_2	127·	..	2	63·5	..	..	·0064912
GOLD (*ic*) ..	Au	197·	197·	3	65·7	..	..	·0067126
„ AUROUS ..	..	..	..	1	197·	..	..	·0201378
HYDROGEN ..	H	1·	1·	1	1·	6726 6841	4802 4721	·0001022
IRON (*ous*) ..	Fe	56·	28·	2	28·	6565 7510	6491 9857	·0028622
„ FERRIC ..	Fe_2	112·	..	6	..	..	..	..
LEAD	Pb	207·	103·5	2	103·5	.. 5494	.. 8880	·0105800
MANGANESE ..	Mn	55·	27·5	2–6	..	..	..	..
MERCURY (*ic*)	Hg	200·	100·	2	100·	.. ..	5793 ..	·0102222
„ MERCUROUS	Hg	..	..	1	200·	..	..	·0204444
NICKEL	Ni	59·	29·5	2	29·5	..	..	·0031155
NITROGEN ..	N	14·	14·	3	4·7	..	..	·0004884
OXYGEN	O	16·	8·	2	8·	..	..	·0008187
PLATINUM (*ic*)	Pt	197·	98·5	4	49·25	..	..	·0050345
POTASSIUM ..	K	39·	39·	1	39·	.. 15135	20740 19996	·0039867
SILVER	Ag	108·	108·	1	108·	.. 1214	.. 6908	.0110400
SODIUM	Na	23·	23·	1	23·	.. 14593	.. 18785	·0023511
SULPHUR ..	S	32·	16·	2–6	16·	.. 3526	— —	·0016355
TIN (*ous*) ..	Sn	118·	59·	2	59·	6654	6297	·0060311
„ STANNIC ..	..	..	..	4	118·	..	..	·0120622
ZINC	Zn	65·2	32·6	2	32·6	8394 8427	10080 9985	·0033324

TABLE XIV.—FORCE OF COMBINATION OF OXIDES AND ACIDS.

Oxide of	Sulphuric.	Nitric.	Hydrochloric.
Ammonium	2759 2916	2422 2715	2422 2687
Copper	.. 1533	.. 1271	.. 1274
Iron	.. 2158	.. 1915	.. 1951
Lead	..	1767 1834	.. ..
Potassium	3157 3193	2898 3079	2839 2989
Silver	..	.. 1370	.. ..
Sodium	3216 3139	2779 3034	2918 3003
Zinc	2343 2076	2041 1652	2104 1649

In the case of chlorides there is a certain complication, as several actions have to be considered. (1) The actual combination of HCl, which Table XIII. Column VIII. gives 4721. (2) As this is a gaseous body, its union with water gives further 3258 in forming the actual acid. (3) The heat of oxidation. (4) The union of acid and oxide. But we have now two products, the salt and water, and therefore the heat of this latter must be deducted to ascertain the energy of the salt itself; and this again includes the heat + or − as the case may be, of the act of solution of the salt.

1. HCl .. .. 4721 }
2. Solution .. .. 3258 } 7979

The formulæ (equivalent notation) now give the several further stages, taking for examples zinc and sodium:

a. *b.* *c.* *d.* *e.*

$$ZnO + HCl = ZnCl + HO.$$
$$NaO + HCl = NaCl + HO.$$

a. XIII. = ZnO	8427	NaO	14593
b. XIV. =	1649		3033
c. Above	7979	HCl	7979
	18055		25605
e. XIII.	6841	HO	6841
d. ZnCl	11214	NaCl	18764
Solution +	1242	—	103
	9972		18867

The last figures agree closely with those of the anhydrous chlorides, of which the zinc gives out heat in dissolving, and the sodium produces cold.

I have in this way calculated the salts in solution, and Column III. Table XV. is the force thus obtained of the several chlorides, while Column IV. is the force developed by simple combustion in chlorine gas. In this table I have given the forces in equivolts as well as foot-pounds, for use in after calculations. A similar process would, in the case of sulphates, be more accurate than the one employed, if we knew the real energy of formation of SO_3, because, when uniting the acid and base we form water, as well as the salt. I have omitted nitrates, because the reactions vary greatly, and full data are not attainable.

TABLE XV.—ENERGY OF PROTO-SALTS.

I. Basyl or Metal.	II. Sulphates.		III. Chlorides.		IV. Chlorides by Combustion.
	Ft.-lb. per gr. equivalent.	Equivolts E. M. F.	Ft.-lb. per gr. equivalent.	Equivolts E. M. F.	
Copper	5878·	1·258	6857·	1·467	5861·
Hydrogen ..	8917·	1·919	7979·	1·707	4523·
Iron	9668·	2·069	10599·	2·268	9857·
Zinc	10503·	2·248	11214·	2·400	9985·
Sodium	17732·	3·795	18764·	3·996	18785·
Potassium ..	18328·	3·913	19262·	4·121	19996·

Is it not obvious that, by attaching figures like these to chemical symbols, we give them a new meaning and force? if the principle were fully carried out, how clear reactions would become. Why is it that iron and zinc decompose sulphuric acid while copper and silver do not? The tables answer us; the specific energy, i. e. the attraction of copper and silver for sulphuric radical SO_4 is less than that of the hydrogen in the proportions shown, while that of iron and zinc is greater. If the deficient energy is supplied by heating, then copper and silver will react upon the acids: for the same reason nascent hydrogen or sulphuretted hydrogen can precipitate the metals above hydrogen in the list, but not those below in acid solutions. Every chemical reaction is capable of similar measurement, and the day will come when we shall know just as well the mechanical equivalent of energy in such reactions as we now do the mass of matter taking part in them.

255. SUBSTITUTIONS OF BASES.—It follows from what we have seen that if, instead of directly combining two radicals, we substitute one for another, the force of the reaction will be equal to the difference between the attractions; and thus, if we exchange

radical for radical in a descending series, at each step we get an instalment of energy set free, and it is found that these instalments bear a distinct relation to the electromotive force of batteries so constituted. The action of the Daniell's cell, which serves as a convenient starting point for measurement, is simply the substitution of zinc for copper, for zinc is dissolved at one plate, and copper is deposited at the other: the specific energy, therefore, is

Sulphate zinc	10503
„ copper	5878
	4625

Andrews gives 5450 as the result of his experiments, but what the actual figure is, awaits more definite trials.

However, we know pretty surely the amount of electromotive force this reaction gives, viz. 1·079 volts, and Table XVI., with the preceding ones, will give readers pretty well all the information at present attainable; the upper figures are derived from those given by Andrews in calories per gramme as the result of his experiments; the lower ones I have calculated from Favre's figures in the previous tables, and in the last column I have calculated these forces in volts, as compared with that of the Daniell taken as datum.

TABLE XVI.—FORCE OF DISPLACEMENT OF METALS.

Metals Displaced.	Metals Substituted.			Calculated in Volts.
	Lead.	Iron.	Zinc.	Zinc.
Platinum	..	..	17605 ..	3·485 ..
Silver	.. 9389	.. 8454	9127 9414	1·807 ..
Mercury	..	..	6616 ..	1·290 ..
Copper	1685 ..	3719 3331	5450 6158	1·079 ..
Lead	..	..	3743 ..	·741 ..
Hydrogen	..	.. 2827	3676 3662	·730 ..

256. **ELECTROMOTIVE FORCE AND SPECIFIC ENERGY.**—Having now, as far as present knowledge permits, ascertained the energy of the various reactions employed in electricity, we have to discover how this energy is changed into an electric current, and to do this we must first ascertain the value in foot-pounds represented by the

volt—the measure of electric tension. Now it is obvious, that this being a static measure, can no more be expressed by itself in foot-pounds than can the energy of a ton weight resting on the ground; with the tension must be united time or motion.

Just as the attraction of gravity acting through a unit of space furnishes the mechanical unit the foot-pound, so a unit E M F, a volt, acting through a unit resistance, an ohm, will give us a unit of electric energy if we employ some unit which shall take in it the position which the pound takes in the mechanical unit. The considerations dwelt on (see §§ 195–7) show us that the only proper element for this purpose is that quantity of matter to which Nature herself connects electricity, viz.

$$\frac{\text{Atom}}{\text{Valency}} = \text{electric equivalent.}$$

Any system of weights may of course be used, and when (as must some day be) this conception is adopted as a fundamental scientific principle, of course the gramme or decigramme will be used. At present and here, I of necessity use that weight which is used throughout, the grain equivalent or chemic current.

A veber of current is the effect of one volt in a circuit of one ohm during one second, and this current is equal during the same time to 5·68 chemical units, or in ten hours produces 5·68 equivalents of chemical action measured in grains, see § 242.

The energy developed in or absorbed by a circuit is in the ratio of the square of the current, or, what is the same thing, of the electromotive force producing the current. This energy or work may be measured as heat, or in mechanical units; and the value for a veber under unit conditions is in calories ·24065, which for ten hours gives

Veber equivalent, calory ·24065	1·3813859
Calories to foot-pounds, 3·0639 ..	0·4862768
Ten hours = 36000 seconds ..	4·5563025
Foot-pounds	4·4239652 = 26544
÷ 5·68	0·7543483
Foot-pounds per volt equivalent..	3·6696169 = 4673

Ten hours divided by 5·68 gives us 6338 seconds as the number of vebers required to effect one grain equivalent of action. Hence we get by the absolute system

Work of veber, absolute units, 1000 ..	3,000,000
Absolute unit in foot-pounds, XVII., l. 3 ..	$\bar{4}$·8676627
6338 vebers	3·8019447
Foot-pounds per 6338 vebers	3·6697074 = 4673

The same result may be obtained in a variety of ways, and each of these calculations (experiments made in figures) furnishes some *data* which, with others similarly obtained, I have transferred to Table XVII. for use in other cases. This result is of supreme importance, for it gives a definite meaning to the volt, which has hitherto been too ideal to grasp, see § 258.

257. CONVERSION OF UNITS.—As facts and figures are variously expressed in different works, and as by the doctrine of the Correlation of Energy, any form of energy is equivalent to, and may be represented in any other form, I give here the values of different units in such form as to facilitate their ready conversion and use in such calculations as the foregoing examples, see § 249.

TABLE XVII.—VALUES AND CONVERSION OF UNITS.

Name of Unit.	Value in	× Decimal.	+ Logarithm.
1. Absolute unit (gm-m-sec.)	Gramme-metre	·101296	¯1·0082849
2. Ditto	Calory	·00024065	¯4·3813859
3. Ditto	Foot-pound	·000737335	¯4·8676627
4. Gramme	Grains	15·434	1·1884785
5. Metre	Feet	3·28089	0·5159916
6. Gramme-metre	Foot-pound	·0072339	¯3·8593721
7. Calory (gm. degree C.)	Gramme-metres	423·55	2·6269047
8. Ditto	Foot-pounds	3·0639	0·4862768
9. Calory per gramme	Ft.-lb. per grain	·198547	¯1·2977983
10. Ditto ditto	Equivolt ditto	·0000425	¯5·6281909
11. Volt (10^5)	Absolute units	100,000·	5·0000000
12. Ohm (10^7)	Ditto	10,000,000·	7·0000000
13. Veber ($10^5 \div 10^7$) per sec.	Ditto	·01	¯2·0000000
14. Ditto (current for equal time)	Chemics	5·68	0·7543483
15. Ditto work of $(10^{-2})^2 \times 10^7$	Absolute units	1,000·	3·0000000
16. Ditto ditto per ohm	Gramme-metres	101·926	2·0082849
17. Ditto ditto ditto	Foot-pounds	·737335	¯1·8676627
18. Ditto heat of ditto	Calory	·24065	¯1·3813859
19. Ditto work for 1 equivalent	Foot-pounds	4,673·	3·6696074
20. Ditto time of ditto	Seconds	6,338·	3·8019447
21. Chemic in 10 hours, § 110	Vebers	6,338·	3·8019447
22. Ditto as current	Veber	·176056	¯1·2456517
23. Ditto work of per ohm	Foot-pounds	822·75	2·9152666
24. Equivolt, § 257	Ditto	4673·	3·6696074
25. Ditto	Absolute units	6337950·	6·8019486
26. Ditto	Gramme-metres	646004·	5·8102353
27. Ditto	Calories	1525·210	3·1833306
28. Ditto (to lb. degree Fah.)	English heat units	6·0523	0·7819901
29. Ditto per grain equivalent	Caly. per grm. eq.	23540·1	4·3718091

258. THE EQUIVOLT.—This is the name I propose for the unit suggested in § 256, which unites the ideas of "quantity" and tension, and connects them as a definite value with the atomic

volt—the measure of
this being a static m
foot-pounds than ea
ground; with the t
Just as the attra
furnishes the mec
volt, acting throu
electric energy i
position which t
siderations dwel
element for this
herself connec

Any syst
must some
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A velo
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equivalent, and so multiply all the actual values given
15·434.
is only a matter of detail; the principle is to express all
rent forces in a single unit, to connect that unit with the
and equivalent constitution of matter used by Nature, and
e the unit itself one which is readily capable of actual
ement and experiment; all this the equivolt does, and while
litates calculations, and will make the different relations of
more readily apparent, it is of course to be converted in a
nt to any other unit by multiplying by the proper constants,
ven in Table XVII., p. 217.

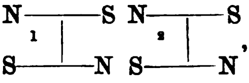
). CONTACT AND CHEMICAL THEORIES.—Having now ascer-
ed, as far as existing data permit, the force generated by various
nical actions, and the force necessary to produce a given electric
ent, and having reduced these to one common measure in foot-
unds and equivolts, we have to learn how the one is converted
o the other.

rom the first days of the discovery of current electricity by
vani and Volta, two theories have been sustained. (1) The
ntact theory, which supposes that at the point of contact of two
similar metals, a disturbance is effected in the supposed normal
stribution of electricity, assumed to be a constituent of all bodies,
nich, extending to bodies in contact, sets up electric and chemical
fects. (2) The chemical theory, which regards the chemical
ctions accompanying the current as the real source of the action.
The last theory is the one now accepted, as the contact theory is wholly irreconcilable with many facts, although it has recently been revived by some of the leading mathematical electricians: the contact theory has indeed many points of fascination for minds of the mathematical type.

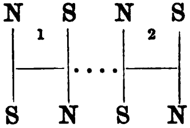
The molecular theory adopted in these pages really combines the truths of the two others in one harmonious system.

Admitting the existence of atoms and molecules as described (§§ 9 and 109), and the possession by them of mutually attractive powers varying in degree with their nature, it becomes self-evident that as soon as any two different substances come within the range of their mutual attractions or in contact, they must exert a disturbing action on the arrangement of each other's constituent particles: those atoms in the two bodies which have the greatest attraction for each other will necessarily turn towards each other, and weaken if they do not altogether overcome the attractions which hold them in their original arrangement: the disturbance thus caused is necessarily propagated to the contiguous molecules; hence is produced a consecutive orderly arrangement called *polarization*, tending to complete a closed chain or circuit, owing to the action of the partially released (or, as it is often, but erroneously, stated, repelled) atoms seeking fresh partners or points of union.

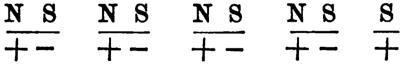
260. Galvanic Circuit.—We may find an illustration in magnetism. We may regard the atom as a small magnetic needle, the molecule as two such needles mounted on a stem with their poles opposed, forming an astatic needle in which the attractions of the several poles satisfy each other; now, this needle being suspended freely, will be indifferent as to position, but if we bring a magnet near, the existing internal equilibrium is deranged, and the astatic needle will place itself in some position due to the external influence; the same will occur if we bring a second astatic or combined system near the first (they being capable of free motion in any direction)—they will arrange themselves thus:



, or



And if a number were so arranged as to place themselves freely, they would form a closed circle of astatic needles, or molecules polarized. Further, if one astatic pair be examined, it would be found that there is an attraction between the two constituents which would be measurable if the wire joining them were a spiral spring, which would be compressed by this attraction; but looking at the second arrangement of the needles above, we perceive at once that as soon as the separate systems exert part of their attractions externally or along the dotted line, the internal bond, the spiral spring, would have less force exerted on it, and the needles would increase their distance; that is, the intramolecular forces are weakened, and an intermolecular attraction set up. A very similar illustration will throw light upon the processes by which we may conceive the transmission of energy as current along the wire. We may imagine a line of equidistant supports carrying magnetic needles, which can therefore turn on their axes but not change place.



Such a system would arrange itself in polar order, and on the presenting of a S Pole, S +, each magnet would in turn revolve and transmit this motion along the line, or if the terminal magnet were forcibly moved a similar action would occur, and by it mechanical energy would be transmitted, losing itself partly on the way by friction; the more distant magnets would also have less effort exerted upon them, under conditions analogous to the fall of tension in a conductor, § 215.

261. POLARIZATION BY POSITIVE METAL.—These ideas are readily transferred to the atoms and molecules of matter, for there is very great reason to believe that every atom is endowed with a species of polarity similar to that of the single needle. A piece of zinc is immersed in sulphuric acid and the molecules in contact instantly arrange themselves thus:

$$\begin{array}{ccc}\overbrace{\mathrm{Zn.\ Zn.}} & \qquad & \overbrace{\mathrm{SO_4,\ H_2}}\\ -\quad + & & -\quad +\end{array}$$

one of the atoms of zinc attracting the sulphuric radical SO_4, and weakening the previous internal attraction of this for the hydrogen which, with the second atom of the zinc molecule, similarly exerting external force, acts in turn upon other molecules, till a complete chain is formed through the lines of least resistance; if we continue the formulæ through the action of a Daniell's cell, that is, through sulphate of copper and a wire, it is easily traced.

$$-\,\rlap{\overbrace{\phantom{\mathrm{Zn.\ Zn.}}}}\mathrm{Zn.}\ \underbrace{\mathrm{Zn.}\ \ \rlap{\overbrace{\phantom{\mathrm{SO_4\ H_2.}}}}\mathrm{SO_4}}\ \underbrace{\mathrm{H_2.}\ \ \rlap{\overbrace{\phantom{\mathrm{SO_4\ Cu.}}}}\mathrm{SO_4}}\ \underbrace{\mathrm{Cu.}\ \ \rlap{\overbrace{\phantom{\mathrm{Cu.\ Cu.}}}}\mathrm{Cu.}}\ \mathrm{Cu.}\ +$$

The upper brackets show the original molecules, the lower one the new attractions exerted and new molecules ultimately formed; the diagram thus shows one atom of zinc removed from one plate and one atom of copper deposited on the other, while the free atoms of zinc and copper propagate the polarization through the connecting wire. A single molecular action is shown here for simplicity, but the full effect can be traced out only in a number of such chains parallel and completed. At present we only seek to examine, not the complete action but the forces engaged in the action of one molecular chain, and the diagram shows it to be the specific energy given up by zinc combining with sulphuric radical, less that absorbed in separating copper from the same radical; energy which appears as heat in ordinary circumstances, as electricity when the polar chain can be formed; in this latter case disruptive action occurs under a degree of force which would not permit direct chemical reactions; in fact, the best practical electromotors are of this class, where the chemical affinity produces, not disruption, but only tendency to it, i.e. polarization, the actual disruption and complete chemical reaction only occurring when the chain, being completed, allows the force to be distributed along it. This, as a fact, is already generally understood, but the process by which it takes place is not, and yet more, the electromotive force is generally set down as holding some direct and simple relation to the specific energy or chemical affinity alone, which is not really the case, § 266.

262. Actions at Negative Plate.—We have seen, § 254, that the total force possibly to be obtained from the equivalent of zinc sulphate is 10,503 foot-pounds, or, the volt being 4673 foot-pounds, we may say that the gross electromotive force of zinc is 2·248 volts, less deductions to be now ascertained. (1) There is the energy absorbed by the substance set free—copper in the Daniell; nitrous gases in the Grove and Bunsen, chromic alum in the bichromate (some of these may be simplified by regarding the process as the liberating of oxygen from prior combination), and most serious of all, hydrogen in the single acid cells. (2) There is the effect of the negative plate itself, and this has hitherto been generally overlooked, although it is well known that the electromotive force of a cell varies with the nature of the negative plate. The theory now under consideration will tell us why. We have seen the zinc polarizing the liquid, but on the same principles every metal would attract the acid radical and tend to produce polarization. Hence the force of polarization produced on the chain is the difference between the two attractions of the metals; this means a struggle between the two metals for the possession of the sulphuric radical, and only the balance of the greater force is available to eject, say the hydrogen, and having done this at an expenditure of 6841 foot-pounds the residue is all that remains to develop into electromotive force, and ultimately into work, and into heat distributed according to the well-known laws of the ratio of the resistance. The total possible force of a Smee or similar cell is therefore—

Total force of zinc ..	foot-pounds	10503 =	volts	2·248
Absorbed by hydrogen	„	6841	„	1·464
		= 3662	„	·784

and from this has to be deducted the counter effect of the negative or collecting plate.

263. Here we have the explanation of the rapid failure of power of the single acid cells, such as the Smee, § 121. The E M F tested in such a way as to prevent its working, as by condensers or against a very high resistance, is much larger than this. Clark gives it as 1·098 and as only ·487 when working; the difference is probably the energy absorbed in rendering hydrogen gaseous; for under the first condition (high resistance and very small cur-

rent) the hydrogen set free does not actually become a gas, it either forms a liquid (metal) film on the plate, or enters into a partial union with it, or is dissolved in the liquids, and the force which would be required to gasify the hydrogen is, therefore, available for electromotive force.

264. In estimating the counter force of the negative plate we require some starting point to fix an actual value on what is otherwise only relative, and carbon offers a material whose counter force is so small that in the general uncertainty of the figures at present available, we may safely count it as nothing, because, although a conductor like the metals, unlike the metals it has no power to replace hydrogen as a base, or to form salts with acid radicals; hence it is that, properly treated, carbon gives the highest attainable force, and that we may assume, without much risk of error, that the force it gives is the force of the + metal, less only that of the substance set free at the − plate. This applies, however, only to nitric acid and similar cells, on account of the great capacity carbon possesses, like platinum, of condensing hydrogen upon its surface.

Taking the value of the nitric acid cells as given by Clark, Table XVIII., and expressing all the forces and actions in the equivolt, we obtain, as a starting point, the force absorbed in decomposing nitric acid.

Total force of zinc	volts	2·248
Carbon in Bunsen cell	„	1·964
Force absorbed by nitric acid ..	„	·284

In the Grove cell, all the conditions being the same except that platinum replaces carbon, we have

Force of carbon	1·964
„ platinum	1·956
Counter force of platinum	·008

These examples show the processes employed in calculating the following tables.*

---

* There are peculiarities hitherto unnoticed in the behaviour of carbon and platinum as negatives. In some experiments I have used two plates of the same size in different reagents. In dilute acids and in chromic acid I found the E M F with carbon one-sixth greater than with platinum. But when the same plates were used in nitric acid, the platinum gave very slightly the greater force. This would indicate a source of the different results by different experimenters: the carbon is known to vary in quality and so does platinum, and besides this there is probably a different relation with each variation of quality, to the acid radicals of different excitants.

TABLE XVIII.—ELECTROMOTIVE FORCE OF CELLS IN VOLTS.

Name.	Positive Cell.		Negative Cell.		Authority.		
	Metal.	Liquid.	Metal.	Liquid.	My Experiments.	Clark and Sabine.	De la Rive.
1. Total force	Zinc	Sulphuric acid 1–12	..	..	2·248	..	..
2. Smee	"	"	Platinized silver	Dilute acid	1·107 ·508	1·098 ·482	·541
3. Wollaston	"	"	Copper	"	·861 ·270	·886	·719 ·536
4. Bunsen	"	"	Carbon	Nitric acid: fuming	See Table XIX.	1·964	..
5. "	"	"	"	" specific gravity 1·38		1·888	..
6. Grove's	"	"	Platinum	" fuming		1·956	..
7. "	"	"	"	" specific gravity 1·33		1·809	..
8. Bichromate ..	"	"	Carbon	100 water, 12 bichromate, 25 acid	1·905	2·028	..
9. Slater's	Iron	Spent solution	"	Nitrate of soda and sulphuric acid	1·096	..	..
10. Marie Davy ..	Zinc	Acid 1–12	"	Sulphate of mercury	1·542	1·524	..
11. Leclanché	"	Sal ammoniac	Carbon with manganese peroxide	Sal ammoniac	1·561	1·481	1·942
12. "	"	Common salt	"	Salt	1·493	..	..
13. Daniell	"	Sulphuric acid 1–4	Copper	Sulphate of copper	1·079	1·079	1·079
14. " telegraph	"	1–12	"	"	..	·978	..
15. "	"	"	"	Nitrate of copper	..	1·000	..
16. Silver chloride ..	..	..	Silver	Zinc chloride	..	1·195	..
17. Lead	..	..	..	..	..	·578	..
18. " sulphate ..	Zinc	Acid 1–12	Copper and lead	Sulphate of lead in acid	·550	..	..
19. " peroxide ..	"	..	..	..	..	..	2·446
20. Grove's gas ..	Platinum	Hydrogen	Platinum	Oxygen	1·5	..	2·518
21. Chromate of lime	Zinc	Dilute acid	Carbon	Calcium chromate	2·070	..	..

265. **Electromotive Force of Cells.**—Table XVIII. is compiled from various sources, as there is a great difference in the values given by different authorities. My own determinations, made for the calculations now being considered, were made with a sine galvanometer through a resistance of 1500 ohms, and with the apparatus described, § 269. They only claim approximate accuracy, but answer the purposes for which they are used.

Table XIX. shows the electromotive force of Grove's cell under different conditions; it is derived from Poggendorf, and is very instructive. The different force given by the acids in different degrees of dilution well illustrates the mode of conversion of specific energy into electric force. As we mix the acid with water it develops heat, and this means loss of potential energy, therefore a diminished amount available for use; for the same reason heating the liquids increases electromotive force. Still my own experiments do not show that this source of force produces anything like the effect shown in lines 11 and 12 of Table XVIII., on the authority of Clark and Sabine; I find that the dilution of the excitant sulphuric acid seems to affect mainly the resistance rather than the E. M. F.

Table XIX.—Force of Grove's Cell.

Zinc in Sulphuric Acid.	Platinum in Nitric Acid.	Force.
Specific gravity 1·136	Concentrated	1·955
„ „ 1·136	Specific gravity 1·33	1·809
„ „ 1·060	„ „ 1·33	1·730
„ „ 1·136	„ „ 1·19	1·681
„ „ 1·060	„ „ 1·19	1·631
Sulphate of zinc	„ „ 1·33	1·673
Common salt	„ „ 1·33	1·905

I have found in all cases, as shown in the last line, that solution of salt in contact with acids gives a higher electromotive force than sulphuric acid does, this being due to the reaction of the two liquids upon each other, which comes in aid of the zinc. It will, however, give higher current only when the external resistance is large, as its own greater resistance counterbalances the extra force it generates. A glance at Table XV. will explain this, as Col. III. shows that the force of chlorides in solution is greater than that of sulphates except in the case of the acids themselves: the consequence is that sulphuric acid acts upon salt, the chloride of sodium, and metallic chlorides are produced together with sulphate of soda, and this extra force is added to that of the circuit, as it is in the same direction.

Table XX. contains my own experiments on the nitric acid and similar cells, arranged to show both the effect of different oxidizing agents, and also the effect of different metals as positives:

Table XX.—Forces of Electromotors.

I.	II.	III.	IV.	V.
Negative Cell.	Positive Cell.	Electromotive Force.	Total Force of Positive.	Loss by Reaction.
Platinum.	Sulphuric Acid 1 to 10 water.			
Nitric acid, sp. g. 1·324	Zinc	1·761	2·248	·487
,,	Iron	1·184	1·671	,,
,,	Copper	·786	1·273	,,
,,	Silver	·678	1·165	,,
Nitrate of soda and sulphuric acid	Zinc	1·540	..	·708
,,	Iron	1·096	..	..
Bichromate of potash ..	Zinc	1·905	..	·343

266. Force of Positive Metals.—From the force given by each combination in Table XX., and using the force of zinc already obtained by calculation from Favre's experiments as the starting point, the value of other metals is readily arrived at. Taking 2·248 volts or equivolts as the total value of zinc, the actual force generated under any given conditions gives the loss or force absorbed by those conditions. In the Grove we have 2·248 − 1·761 = ·487; all the conditions, except the positive metal, remaining unchanged this is a constant loss, and by adding it to the actual force each metal yields, we evidently obtain the total force that metal can generate. I give in Table XXI. the results of several such processes, and also the value derived from Favre's figures of the sulphates.

Table XXI.—Force of Positive Metals.

Single Cell.	Zinc.	Iron.	Copper.	Silver.
Table XXIII., Col. II. ..	2·248	1·723	1·280	1·174
Daniell's	,,	1·702	..	..
Grove's, XX., Col. IV. ..	,,	1·671	1·273	1·165
Favre, XV.	,,	2·069	1·258	..

These figures agree among themselves more closely than those given by different authorities for the same experiments; but iron presents an anomaly, owing, probably, to its capacily for forming two sets of salts. However, while Favre's figures make its value 2·069, Andrews' give it as 1·888, so there is obviously room for further information.

267. COUNTER FORCE OF NEGATIVES.—It was pointed out in § 262, that while the chemical action at the positive metal is the source of the electromotive force, there are two actions at the negative plate which diminish or absorb part of this force; the first of these is the opposing power of the negative plate itself, which we may call the counter force of the negative. This can be ascertained, like the positive force, by keeping all conditions constant except the negative plate. Table XXII. gives the forces produced by both sets of changes at one view.

TABLE XXII.—FORCE OF METALS IN SULPHURIC ACID.

Negatives.	Positives.			
	Silver.	Copper.	Iron.	Zinc.
Platinum	·293	·399	·842	1·367
Silver	..	·139	·582	1·107
Copper	..	..	·236	·861
Iron	..	..	..	·558

The platinum line and zinc column are the observed figures; the others are calculated from them. The forces are those produced against such resistance as prevents the formation of gas; by deducting ·583 from them we get the force under working conditions (§ 262), though here, again, iron shows a discrepancy, as it would appear that iron and zinc would not produce a working current, though in fact they do.

As the full force of zinc is 2·248, and 1·367 is the highest actual force, we have 2·248 – 1·367 = ·881 as the constant quantity to deduct from the total loss which each negative metal shows in the same way with zinc; thus silver and zinc give 1·107, which, taken from 2·248, leaves 1·141 – ·881 = ·260 as the counter force of silver. In this way Column III. of Table XXIII. is obtained.

I may here remark that platinized silver, though coated with platinum, acts precisely as silver so far as the force is concerned; its value is in throwing off the gas, and so diminishing resistance; and hence it would appear that it is more economical in the long run to use platinized platinum than the cheaper silver always used.

Columns IV. to VII. of Table XXIII. show the net force due to the metals of each combination; that is, deducting the counter effect of the negative plate, but not that of any chemical reaction, which is considered separately in next section. Some writers say that this relation is constant for all liquids, but this is entirely misleading; it is wholly a matter of chemical reactions, and the relations may even be reversed; thus iron is positive to copper in acids, but copper is positive to iron in sulphide of potassium and other liquids. See § 164, p. 117.

The figures in the table are based on sulphuric acid, but are approximately correct for all the ordinary combinations, as may be seen by Table XXI.:

TABLE XXIII.—FORCE OF METALS IN VOLTS.

I.	II.	III.	IV.	V.	VI.	VII.
Names.	Total as Positives in Sulphuric Acid.	Counter Force as Negatives.	Force of Positives as opposed to Column I.			
			Zinc.	Iron.	Copper.	Silver.
Carbon	0	0	2·248	1·723	1·280	1·174
Platinum	(?)	·008	2·240	1·715	1·272	1·166
Silver	1·174	·260	1·988	1·455	1·010	..
Copper	1·280	·506	1·742	1·209	..	..
Iron	1·723	·809	1·439	..	..	..
Zinc	2·248	..	0	..	..	..

268. CHEMICAL COUNTER FORCE AT NEGATIVE PLATE.—The second deduction from the electromotive force is the chemical action in the liquid in contact with the negative plate. In § 262 the force of setting hydrogen free is set down as 1·464 equivolts; this is in excess, no doubt, for it is the force of combustion of hydrogen, which includes the latent heat of gasification of oxygen; in full work, however, the batteries do really appear to absorb this amount, for the counter force of hydrogen coating the plate makes it up. Taking the force when hydrogen is not actually set free as gas, we may obtain the latent heat or energy of gasification.

Force of Smee observed	1·107
„ silver zinc, Table XXIII.	1·988
Difference = absorbed by hydrogen	·881
Force of combustion of ditto	1·464
Probable latent energy of gases	·583

This is the deduction to be made from Table XXII. to get the working force. By similar processes we can obtain the energy absorbed in each of the different actions, and thus is formed Table XXIV.

TABLE XXIV.—FORCE ABSORBED IN NEGATIVE REACTIONS.

		Equivolts.
Single cells:	free hydrogen	1·464
„	liquid ditto	·881
Nitric acid:	fuming	·284
„	specific gravity 1·38	·360
„	„ 1·33	·430
„	„ 1·32	·479
Nitrate soda and sulphuric acid		·708
Bichromate potash		·343
Manganese peroxide		·687
Copper in Daniell		·506

By deducting the proper one of these figures from the proper one in Table XXIII., every information can be obtained as to the proper mode of forming batteries, and much waste of time and money may be saved in testing any idea which occurs as to a probable combination; if the requisite metal or liquid is not in the tables, the first thing to do is to make a simple experiment, and add the result to the proper table. Such a process would at once dispose of many of the crude ideas which suggest themselves to experimenters.

The figures in all these tables refer, of course, to the perfect condition of things, and at first starting; in all cases the changes which occur in action soon reduce the force.

269. APPARATUS FOR EXPERIMENTS.—As some readers may wish to make experiments on the electromotive force of chemical combinations, I will describe the apparatus and process I have, after many trials, found most convenient, the object being to exchange one part for another rapidly, and without confusion or mixture of substances.

(1) A stand fitted with two binding screws for the wires to go to the galvanometer and resistance, which connections may thus remain undisturbed for any required time: the screws are connected to two mercury cups into which the wires from the elements dip, thus permitting these to be instantly exchanged.

(2) A U tube of glass or wood cemented, or, what is the same thing, a vessel with a partition descending nearly to the bottom; this contains dilute sulphuric acid or any other liquid which is suitable to the other liquids to be employed at the two elements which it serves to connect.

(3) A number of small porous tubes (3 × 1 inch are suitable) capable of being supported in the U tube at the proper height.

(4) The various metallic plates are each fitted with a wire of such length as to dip into the cups on the stand while the plate is suspended in the porous tube.

This apparatus permits the exchange of each of its constituents in an instant, and in trying various liquids there is little disturbance by endosmose, as the two porous cells containing them are immersed in a bath of intervening liquid. Of course, for experiments with manganese, sulphates of mercury, &c., a porous cell is to be mounted for each substance; and in comparing nitric acid and other oxidizors, &c., a clean carbon must be used with each liquid, but platinum is better, if washed and made red hot. Either a tangent or sine galvanometer may be used, and in either case the first thing to do is to ascertain what deflection is equivalent to a force of 1 volt, as described § 176: or such a galvanometer as the universal instruments, §§ 179, 180, simplifies matters by showing the results direct upon the dial itself.

270. To Measure Electromotive Force.—This has to be done in the terms of some standard cell, usually the Daniell, the force of which is known, but if the exact resistance, internal and external, of the circuit and the current generated be known, Ohm's formula $C \times R = E$ gives the force in volts, but as the force and resistance are constantly altering in a working battery, this process gives us the actual force at the time, not the *potential* E.M.F. of the battery.

(1) With a delicate galvanometer, on which a fixed deflection can be obtained, the force of any cell or battery will be proportional to the resistance, including of course that of the galvanometer, &c. If the resistance is made very large the internal resistance of the cell may often be neglected if not known.

(2) The same process may be used with small resistances and full currents, but in that case the internal resistance must be included in the totals. Both rules depend on the law that for equal currents the force is in direct proportion to the total resistance. By carefully measuring the total resistance in the case of a Daniell cell and dividing this by 1·079, we get a constant representing the force of 1 volt, and dividing the resistance which with any other cell gives the standard fixed deflection (on the same instrument, of course) by this constant, we get the force of the cell under trial in the same manner as described more fully below as to Wheatstone's process.

(3) With a very delicate sine or tangent galvanometer and a large resistance, the amount of which need not be known provided it is always the same, the electromotive force is proportional to the sine or tangent of the angle of deflection, and having once ascertained the angle given by a Daniell, and from it that due to 1 volt, the instrument can be marked, or a table made of the

deflections, so as to read off direct in volts the electromotive force causing the deflection. This is the plan used § 269.

(4) Wheatstone's plan is available either with large or small resistances: it depends on the production of two constant deflections. In this and the following cases I will use in the formulæ capital letters for the standard cell and small letters for the one to be measured, E, *e* being force in volts, R, *r* resistance in ohms, C, *c* current in vebers, B, *b* the standard cell and that to be measured.

A is connected with such resistance as is necessary to produce the first fixed deflection, say 20°, and a further resistance, R, is added sufficient to bring the deflection to a second fixed angle, say 10°.

a is now arranged to give 20°; the resistance required for this need not be measured, as it will vary with the internal resistances and has nothing to do with the calculation: further resistance, *r*, is now added to bring the needle to 10°, then $e = E\,\frac{r}{R}$ in volts.

This may be simplified by once for all ascertaining the resistance value of 1 volt, and I will exemplify this by an experiment.

A large Daniell with an external resistance of 2·41 ohms, and a total resistance of 2·91, marks 20° on a galvanometer; an extra resistance of 3·11 brings it to 10°. Of course, it will require the same total resistance with every other Daniell, large or small, to reproduce these deflections, but the external resistances will be different in all cases for the first deflection; the second extra resistance will be always constant: it is, therefore, a figure representing 1·079 volts on this instrument between these angles, then 1·079 : 1 ∴ 3·11 :: 2·882. This gives the resistance equivalent to 1 volt, and all future experimental resistances divided by this give the force of the cell under trial—for instance, a Smee cell in full work took 1·35 extra resistance to bring the needle from 20° to 10°. The formula works out thus:

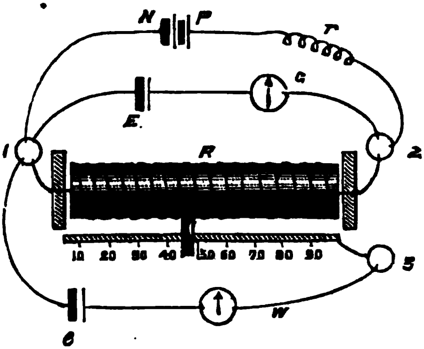
$$1{\cdot}079 \times \frac{1{\cdot}35}{3{\cdot}11} = {\cdot}468.$$

By using the constant obtained at the first experiment, the multiplying by 1·079 is for ever after unnecessary, for $\frac{1{\cdot}35}{2{\cdot}882} = {\cdot}468$. This is the simplest and best plan for obtaining actual working forces at any time.

(5) Clark's potentiometer is, perhaps, the best mode of measuring the absolute tension or potential of a cell or battery. It is an instrument resembling Wheatstone's rheostat (Fig. 50, p.

157). In fact, by a slight modification the rheostat may be easily made to serve the purpose, as I will show.

FIG. 65.



R is the rheostat, to which an extra binding screw is to be added to provide two circuits, from 1 through the whole wire to 2, and also from 1 through part of the wire to the travelling contact, and thus to 3. Any other apparatus may be used, even a long fine wire fixed over a scale along which the wire shown as connected to 3 may be moved.

E is a standard battery connected through a galvanometer, G, as shown; N P is another battery (both should be constant) connected with a resistance, *r*, which is to be varied till these two batteries exactly balance, and the galvanometer, G, shows no deflection. *e* is the battery to be measured, and is connected as shown (all three negative wires connected together at 1), through a galvanometer to the shifting contact at 3.

The effect is that in the wire of the rheostat or potentiometer we have every degree of tension from *o* up to that of E, say 1·079 volts, if E is a Daniell: therefore as the shifting contact is moved by revolving the rheostat core, *e* has opposed to it every degree of tension, and a current will pass from or to it until the contact reaches the point of the wire in which the permanent tension is equal to that of *e*, when the galvanometer returns to *o*, and the scale will give the tension in parts of that of E, and this being known, that of *e* is calculated from it. It would be easy, if a standard cell or battery were once fixed upon, to arrange the wire of the instrument so as to divide it into the actual volts of this cell, and then all future experiments would be read off direct without calculation.*

---

* In the more recent forms of the instrument this plan has been adopted, and the cell described § 162 is used as the standard.

When the force of *e* is greater than that of E their positions are to be exchanged.

Clark says that by means of a mirror galvanometer and a careful graduation of the instrument it is easy to measure tensions to the ten-thousandth or even hundred-thousandth part of a Daniell cell.

(6) *By Condensers.*—The force of cells may be compared by the several charges they can give to a condenser, but this process is one most useful in such technical work as testing cables, and those employed in such work will have access to those books which enter into this class of subjects more completely than is possible or necessary here.

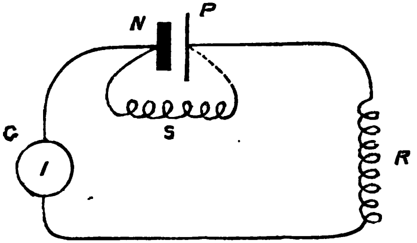
271. MEASUREMENT OF INTERNAL RESISTANCE OF BATTERIES.

(1) *By Ohm's Formula.*—This may be ascertained by Ohm's formula when the electromotive force and current are known, for $\frac{E}{C} = R$. This is the total resistance, and deducting the external gives us the internal.

(2) *By Sine or Tangent Galvanometer.*—By means of any known resistance produce a deflection; add further resistance until a deflection is produced whose value in current is exactly half that of the first. As the current is halved, it is clear the resistance has been doubled—i. e. the second resistance is exactly the same as the first; therefore it is only necessary to deduct from this the known external resistance, including, of course, that of the galvanometer and connections, and the residue is the internal resistance.

(3) *By a Shunt.*—This process, devised by Mr. Desmond Fitzgerald, is by far the simplest. Prepare a shunt or connecting wire, the resistance of which is exactly the same as the sum of all the other external resistances—viz. the galvanometer, which may be of any kind, and all the connections (and if any work is doing, the resistance of that also). Fig. 66 will now make all plain.

FIG. 66.



First connect as shown, so that the current from the battery N P divides itself through the two equal resistances, (1) S, the shunt,

(2) through G, the galvanometer, and R, the resistance instrument, and note very carefully the deflection at G.

Now disconnect the shunt S; the whole current then passes through the other circuit, and therefore the deflection at G increases. It will be seen that in this second condition the *external* resistance is doubled, because, by the laws of derived circuits, the resistance of two equal circuits together is just half that of either of them alone, but the *internal* resistance of N P remains unchanged.

Increased resistance is now added at R till exactly the same deflection as at first is produced in G; this extra resistance is exactly equal to the internal resistance of N P, because its addition brings the current to its original amount by doubling the internal resistance, as the removal of the shunt previously doubled the external.

There are several other processes, but they require formulæ and calculations, and I have selected the foregoing modes of measuring both the force and resistance of batteries as the simplest in principle, most readily performed, and accurate in results.

272. Shunts.—These are derived circuits, § 238, and the term is of course derived from the railway process of *shunting* a train on to a second set of rails; it is very useful to have at hand such secondary circuits prepared to correspond with instruments they may be required to be used with. Of course any wire led across connections acts as a shunt for just such part of the current as equals the ratio of the resistance, and therefore a second resistance instrument serves the purpose; but for such uses as that described in last section, it is convenient to prepare a special wire, equal to the known resistance of the galvanometer and fittings intended to be used for the purpose, and coil it up with its ends left just long enough for convenient use, and label it with the purpose it is made for.

For other occasions, shunts are required bearing a known ratio $\frac{1}{2}$, 1-10th, 1-100th, &c., of the circuit they are to be used with. The following formula gives the proportionate resistance in such cases. R is the resistance of the instrument whose indications we desire to multiply, n the multiplying ratio, and S the resistance to be given to the shunt:

$$S = \frac{R}{n-1} \text{ ex. } \frac{53}{100-1} = \cdot 5353.$$

273. Shunts should be made of the same material as the circuit they are used with, so as not to have their ratios disturbed by external temperature, § 223.

It is impossible to avoid the effects of self-heating by the current: in order to have the same action in both circuits the wire of the shunt ought to increase in weight in the same ratio as the current it carries: but for obvious reasons of economy and convenience, this cannot be done: in fact the reverse is nearly always the case; a thinner and shorter wire being used instead of a thicker and longer. Therefore no shunts supplied with galvanometers can be relied on if more than momentary currents are passed through them.

274. **Work or Heat Varies as the Square of the Current.**—The following formulæ give the heat or work developed in any circuit or any part of it by expressing the various factors in their proper units, E in volts, R in ohms, C in vebers, t is time in seconds, and c is the constant in each case representing, in Table XVII., p. 217, the value of a veber's work:

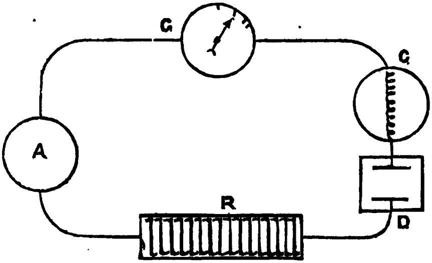
1. $C^2 \times R \times t \times c.$
2. $C \times E \times t \times c.$
3. $\dfrac{E^2 \times t \times c}{R}.$

That is to say, in the same resistance and time, the work of the current varies as the square of the current, or while on the formula $C = \frac{E}{R}$, the current itself under these conditions varies directly in the *ratio of the electromotive force*, the work or heat of the current varies in the *ratio of the square of the electromotive force.*

This is a serious stumbling-block to many (especially when regarding electricity as a fluid) who cannot perceive for what reason, merely doubling the quantity of a fluid passing should endue it with fourfold force; but all the mystery disappears when examined by the light of the molecular theory. Let us, then, study it in a simple experiment measured exactly by the figures we have already obtained.

275. Let us take three exactly similar bichromate cells, A, A^2, A^3, the force of each of which is, per Table XVIII., volts 2·028, the internal resistance taken as ohm 0·2 arranged as in Fig. 67.

Fig. 67.



G is a galvanometer whose resistance we call 0·1, and whose value in vebers is known, §§ 176 and 179.

R is a rheostat or resistance instrument for adjusting resistance and current as required.

C is a calorimeter, such as described § 192, the wire of which has a resistance of 1 ohm.

D is a depositing voltameter with two copper plates and a resistance of ohm 0·200.

The functions of these two should be fully understood: D measures current or "quantity," pure and simple; so long as a given current passes exactly the same weight of copper deposits in the same time, whether 1 or 50 cells be employed, and whether the resistance of D itself be ·2 or 100 ohms. C measures the energy or heating power of the current in a fixed resistance; if its wire be 2 ohms instead of 1, it indicates double work done; but if it be 1 ohm, but the "current" be doubled, then it indicates fourfold work.

276. We wish to obtain through this circuit with one cell a veber current, what must the resistance be? The formula is $\frac{E}{C} = R. \frac{2\cdot028}{1} = 2\cdot028.$

The fixed resistance is	G	·100	
	C	1·000	
	D	·200	
			1·300
A, internal resistance			·200
R, rheostat and connections; to be made =			·528
			2·028

Under these conditions a current of 1 veber passes, and therefore in 6338 seconds 1 equivalent of chemical action takes place throughout the circuit; that is, 32·6 grains of zinc are dissolved in the cell A (independent, of course, of any local action), and in D 31·75 grains of copper are dissolved from one plate and deposited on the other, while in C heat is produced equivalent to 4673 foot-pounds of energy: that is, enough to heat 1 lb. of water a little over 6° Fahr.

We must now assume a few conditions to adjust the experiment to the theory. Let us consider the wire of C as consisting of a single chain of molecules, along which during the solution of an equivalent of zinc 4673 impulses or molecular vibrations are transmitted, each impulse being equivalent to 1 foot-pound of force for each unit of current generated in the chain; these are the conditions of paragraph 3 of the definition of the equivolt, § 258. These figures, though assumed, exactly express the fact, for it is precisely the same in the end whether one single chain represents each action as 1 foot-pound, or whether a million molecular chains transmit each only one-millionth of a foot-pound; the total figures are true either way, but the assumption enables us to form a definite conception of the facts, and to deal with them in simple figures.

Under these conditions we may deal with the force in a simple Dr. and Cr. account, thus:

Dr.		Equivolts.	Ft.-lb.
1 equivalent of zinc		2,248	10,503

Cr.	Ohms.	Equivolts.	Ft.-lb.
Absorbed in deoxidation	..	·220	1,028
As heat in cell:			
Struggle of polarization, *nil*	·000	..	..
Resistance of cell	·200	..	..
Resistance of general circuit, R, D, G	·828	1·028	4,804
Resistance of calorimeter C		1·000	4,673
		2·248	10,505

The value of deoxidation, ·220, is less than that given for the bichromate cell in Table XXIV., but as I am taking the force given by Clark, this necessitates the lessened loss in the reaction; for the present purpose, however, the actual figures are of small consequence so that they are all duly proportioned.

277. We now insert a second cell, A^2, and our force becomes 4·056, the internal resistances ·400, and therefore we reduce that of R correspondingly, leaving total resistance the same; then $\frac{4\cdot056}{2\cdot028} = 2$. Our current is now doubled—that is, G marks a current of 2 vebers per second; D deposits 63·5 grains of copper in the equivalent period of 6338 seconds, or twice as much as before; but C marks heat equivalent to 18,692 foot-pounds, or 24·2 heat units, that is, fourfold force, instead of only double like the rest. Why? There being two units of current there are two equivalents of zinc dissolved *in each* cell. There are two cells, and therefore we have fourfold energy given up by the zinc. But the chain of molecules is unaltered, except that by inserting the second cell we have doubled the strain put upon it, making it 4·056 volts instead of 2·028, and therefore each molecular impulse has a force now of 2 foot-pounds; owing to this doubled energy it over-

comes the resistance in half the time, and therefore the current is doubled.

But the consequence of this is that in the time of the experiment we have now 4673 × 2 = 9346 molecular impulses (which represent the "quantity" or current), each effected under a force of 2 foot-pounds, and as resistance means, and is measured as, the effecting each such impulse in the single time, these conditions imply that the work of overcoming resistance in half the time is, for each ohm of resistance, 9346 × 2 = 18,692 foot-pounds.

We now state the second set of conditions in a Dr. and Cr. account like the first:

Dr.	Equivolts.		Ft.-lb.
Cell A, 2 units of zinc	2·248 2·248	.. ..	10,503 10,503
Cell A^2, 2 units of zinc	4·496	..	21,006
	8·992	..	42,012

Cr.			Equivolts.	Ft.-lb.
Deoxidation 4 units at ·220		..	·880	4,112
Absorbed per ohm:—				
In doubling current	=	2·000	..	..
In doubling force, or halving time		2·000	..	..
	2 × 2 =	4·000	..	..
		Ohms.		
Resistance of cells ..	·400	..	..	..
Resistance of general circuit	·628	1·028	4·112	19,216
Resistance of C		1·000	4·000	18,692
		2·028	8·992	42,020

The slight difference in the foot-pounds is owing to the use of even numbers and neglecting small fractions.

The experiment with three cells would give exactly the same result, except that 9 equivalents of force per ohm are required to maintain a threefold current, and it is needless to occupy space in working it out in detail.

If in the second case we add an equal extra resistance, and so keep the current at the 1 veber as in the first case, we get 1 equivalent zinc consumed in each cell, and the conditions become:

Dr.	Equivolts.
2 equivalents of zinc =	4·496

Cr.		Ohm.	Evlt.	Evlt.
Deoxidation, 2 cells ..		..	..	·440
Resistance:				
Cells		·400	..	..
Circuit	·628	..	..	..
Extra	2·028	2·656	..	3·056
C. Calorimeter		..	..	1·000
				4·496

278. This may be stated in another way, which will exhibit the principle clearly. The units of measure we deal with embrace four elements: (1), weight moved; (2), space moved through; (3), time during which motion is produced; (4), the absolute force operating. The final result in any special case, as compared with the unit standard, will vary in the ratio of each and all of these four elements; time, of course, in *inverse* ratio. The electrical measures are, in fact, linked to these several units. In our present experiment—(1) is a molecular impulse of 1 lb.; (2) is 4673 ft. (and this also under the condition of unit current represents 1 ohm resistance); (3) is the duration of 1 equivalent unit current, 6338 seconds; (4) is the volt, and in unit conditions links all. We have, therefore, in the first experiment of 1 veber current, forces as expressed in line A below; in the second, of 2 veber currents in same resistance, the conditions are expressed by lines B and C, according as we regard the time or the current as the fixed element:

	1. Current.		2. Ohm.				3. Time.		4. Force.		
A	1	×	1	×			1	×	1	=	1
B	2	×	1	×			1	×	2	=	4
C	1	×	1	×	½	=	2	×	2	=	4

279. From all this it follows that, starting with the normal amount of energy expressed in the units, the energy needed to generate current and the energy absorbed in the circuit or in each ohm of the resistance vary as a fact in the ratio of the square of the current passing; but it is very evident also that the statement that the work of a current varies in the ratio of the square of the current is, after all, only a mathematical expression based for convenience upon a single one of the two varying conditions, as with static electricity, § 71, p. 58; for the real fact, as shown in the several

Dr. and Cr. accounts, is that it varies not as the square, but in the direct ratio of the current, that is, of the number of molecular actions in a given time, but that it also varies in the direct ratio of the force under which these actions occur; it is because these two necessarily vary in exactly the same degree, one being dependent on the other, that the combined effect can be truly represented as due to the square of either one of them. The same principle will be found to underlie every action which varies in the ratio of the square of its apparent cause; examination will always discover a second cause operating *pari passu*, as is well illustrated in the laws of falling bodies, which furthermore are strictly comparable with the laws of "current," and its force; for, as before stated, Ohm's laws are simply the old mechanical laws in another form.

CHAPTER IX.

ELECTROLYSIS.

280. The name *electrolysis* (breaking up by electricity) is given to the process of transmission of the electric current through liquids, when accompanied by the disruption of the molecules composing the circuit, the constituent radicals of the molecules being set free at the two poles.

The plates in the decomposition cell are called *electrodes* (electric ways): the plate connected to the + pole of the battery, the copper, platinum, or carbon, is the *anode* (way up, as carrying the current out of the battery); the plate connected to the − pole of the battery, the zinc, is the *cathode* (downward way).

The liquid undergoing decomposition is the *electrolyte*. The molecules of an electrolyte break up into two radicals, which are called *ions* (indicating individuality, and in another sense meaning *going*). These radicals or *ions* form the two classes described, § 109, and illustrated in Fig. 40, p. 85. Those ions which turn towards the anode are called *anions;* they are electro-negative or acid radicals, such as oxygen, chlorine, SO_4, &c. Those which turn towards the cathode are called *cations;* they are electro-positives or basic radicals, as hydrogen and metals. The same ion may belong at different times to each of these classes, if united to one having a higher individuality in either direction, for there is no direct attraction between the electrodes and the ions themselves, but the relation depends simply upon the temporary polarity they assume in the circuit.

Ions or radicals may be single atoms, or compounds which act as radicals chemically, and these may even be incapable of actual separate existence, as far as present knowledge goes. HCl is an electrolyte composed of two single atoms; in H_2SO_4 two atoms of hydrogen form one ion and the compound radical SO_4 the other; this radical cannot exist uncombined, so that sulphuric acid is an electrolyte only when in presence of something it can react on, and combine with, such as water, although water itself is not an electrolyte. Ammonium NH_4 is also a compound ion strongly resembling potassium in its properties; it also cannot exist free, but breaks up into NH_3, ammonia, and H, giving an *apparent* exception to the law of equivalence by producing two free substances, each equivalent to the current producing them; but it must be considered that ammonia is not really a radical, for NH_3 is a complete molecule of the order described, § 10 (1), p. 7, and is not capable of replacing H in salts.

281. We must regard the circuit as consisting of chains of molecules; some metallic, as in the plates and conductors; some liquid, as in the cells; and the transmission of electricity as consisting of a motion of each molecule in the chain, accompanied with a breaking in halves of a molecule wherever the current passes from metal to liquid, or *vice versâ*. We shall thus understand why there is equal current, equal quantity of electricity, or equivalent chemical action at every section of the circuit, as stated, § 111, p. 86, because there are the same number (or value, as will be seen presently) of molecular actions effected at every part, however the molecules themselves may differ in nature. Each cell is, therefore, a section of the conductor, and each has its own specific resistance just as the wire portion has. But the cells are of two orders in another respect.

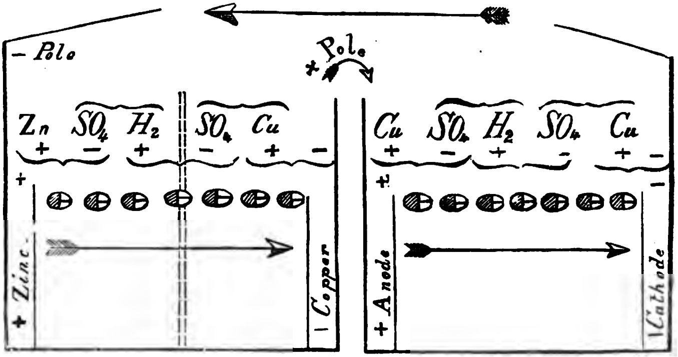
(1) Generating cells, in which energy is set free by chemical actions, and becomes electromotive force, setting up the current as explained Chapter VIII., §§ 256–268: these are battery cells, and stand for E in formulæ.

(2) Decomposition cells, in which energy is absorbed in doing chemical work. These may be simple resistances, where no ultimate change is made in the solution; such are most electro-metallurgical processes where the same metal is dissolved from the anode as is set free at the cathode. But if any *ions* are actually set free by the current, they tend to recombine and act as a cell of the first order with their electromotive force opposed to that of the battery, and stand as $-e$ in formulæ. The feeblest E M F will send a current through the first of these classes of decomposition cells, but the second class require an E M F greater than that set up by the action itself, or electrolysis cannot take place, for reasons explained, § 289.

Except for this distinction of generating and decomposing cells, all the cells are under the same conditions. In each cell there is a + plate or element, the zinc in the battery cells and the anode in the decomposition cells, and if the latter can unite to the chlorous radical of the electrolyte it dissolves just as the zinc does in the battery cells. In each cell there is the electrolyte, which gives up its chlorous or − ion at the + plate, and transmits the molecular motion which constitutes the current to the − plate where it also gives up its + ion. The − plate then continues as the + pole or anode to the next cell, and ultimately to the – pole or first zinc of the battery to complete the circuit. In fact, each pair of connecting plates in separate cells, acts as though it were a metallic partition separating the two liquids with which the plates are in contact. In such a plate, or conducting partition, one side would be + and the other side –, and the two plates in different cells correspond to these two sides, connected together by a connecting wire instead of by the mass of metal of a plate itself. It is of the utmost importance to bear in mind this distinction of *plates* or *elements*, related to the liquid within their own cell; and *poles* or *electrodes*, related to another cell and to the direction of the polarity they set up, or the current they transmit. Therefore, keeping out of sight the distinction of cells as those setting up and those absorbing energy, that plate in each cell which is + to its own liquid, or the positive *plate* of the cell, is the anode or + electrode of the cell to which it is connected, and completes the circuit from the – plate of this cell. Hence it is that the anode in the decomposition cell represents the zinc in the battery cell, for like the zinc it is + to the liquid, and gives up energy to the liquid (though that energy is derived from the current itself in this cell), and like the zinc it dissolves if made of materials which can combine with the negative or – radical of the solution. For this reason some prefer to call the anode the *zincode.*

Fig. 68 exhibits these relations, in the actions of a Daniell cell and an ordinary coppering arrangement.

Fig. 68.



It shows the polarization set up in the complete circuit from the zinc in the liquid, with equivalent actions resulting in both cells, the upper brackets showing the original arrangement of liquids, the lower ones the effect of the action. At the + plates to the left in each cell, zinc in the battery, the anode in the decomposition cell, an atom of metal is removed from the plate; the intervening molecules transmit the action, and absorb the ion originally united to the first acid radical; and in each cell, at the end of the chain in contact with the negative plate or cathode, there is set free a positive radical; in this case copper in both cells. This diagram is arranged to furnish several illustrations of the laws of electrolysis, and should be studied in connection with Fig. 40, p. 85, which more fully explains the ideas to be associated with the ellipses in Fig. 68; these represent the molecules and their constituent radicals or ions, expressed also in the chemical formulæ, while the symbols + and – show the classes of radicals, + being the cations, and – the anions; their arrangement exhibits the order of polarity set up, while the arrows show the direction of the current within the cells and in the outer circuit.

282. The laws of electrolysis usually accepted are those of Faraday, who also originated the terms described. These laws are—

I. *No elementary substance can be an electrolyte.*—That is to say, the two ions must be differently composed.

II. *Electrolysis occurs only while the body is in the liquid state.*—This state may be due to either fusion or solution; in the latter case many substances become electrolytes by a *secondary* action, which are not so of themselves.

III. *During electrolysis the components of the electrolyte are resolved into two groups; one group takes a definite direction towards one of the electrodes, the other group takes a course towards the other electrode.*—They turn towards the several electrodes in polar order, but are not attracted or moved towards them. Faraday held that only substances containing single equivalents of each radical could act as electrolytes, but this is now superseded by more general conceptions.

IV. *The amount as well as the direction of electrolysis is definite, and is dependent upon the degree of action in the battery, being directly proportional to the quantity of electricity in circulation.*—This law is explained by § 283, which shows that "quantity of electricity" means number of equivalent molecular actions.

V. *Those bodies only are electrolytes which are composed of a conductor and a non-conductor.*—This addition of Miller's is useful to remember, but can scarcely take rank as a law or principle of nature.

283. It is of importance to learn what is the quantity of matter which constitutes the equivalent; it is generally considered that it is what used to be called the chemical equivalent. If this were

true, and if Faraday's theory were also true, that only molecules consisting of one equivalent of each radical are electrolytes, the old equivalent theory of chemistry would be almost impregnable; but neither of these ideas is true. The equivalent or lowest combining proportion of nitrogen is 14, that of hydrogen being 1; but when pure ammonia is electrolyzed, only 4⅔ of nitrogen is given off for one of hydrogen. When cupric chloride $CuCl_2$ and cupreous chloride Cu_2Cl_2 are electrolyzed in series, the first gives one equivalent and the second two equivalents of copper for the same current which, in the battery or other cell, gives one of hydrogen.

The new atomic notation of chemistry is based, not only on the facts of chemical combination, but also on the relation of different substances to the forms of crystallization, and to the properties of isomeric and isomorphous bodies; and this view of the constitution of matter also completely covers the facts of electrolysis. It bestows upon the different atoms different combining powers, as the quantities represented by these atomic weights can combine with, or replace, one or more atoms of hydrogen. This property is called the valency of the atom. But the atoms are not only capable of entering into union singly as *ions*, but two (or more) of the atoms of the same element can first unite (in which case they usually condense a portion of their combining powers) and constitute a fresh *ion* or radical, having its own proper valency. The theoretical explanation of this, known as the doctrine of "atomicity," is given in § 6, p. 3; but this doctrine is by no means essential to the comprehension of the facts, nor do the laws derived from these facts depend upon the doctrine of the possession of atomicities by the atoms. These chemical relations have been examined in previous pages from various points of view as occasion required, but they are the basis of electrolytic actions, and their comprehension is essential in the study of the subject of this chapter; they are therefore reviewed here, even at the risk of some repetition. It is, however, unnecessary to enter into the subject of "atomicity," or to consider whether that doctrine is true or wholly imaginary, or a partial conception which may hereafter develop into a more perfect theory by aid of the revelations of the spectroscope. What we have to do with is *the fact* that the several weights called under this new system the *atomic* weights, do represent in combination chemically, one, two, three, or more atoms of hydrogen. Again, it is a fact that molecules do exist which, in the gaseous state, contain the elements in these ratios by volume; thus HCl hydrochloric acid, H_2O water, H_3N ammonia, each contain these relative volumes of H for one volume of the other gas: when combined they, every one of them, occupy two volumes, the same volume, that is, as the molecule of hydrogen H H, and these molecular volumes hold all alike the same relation to energy, for they expand equally for equal heats and pressures. All these manifold points of agreement justify the conclusion that these weights are the atoms, and that the molecules are constituted by the union of these different numbers of atoms. *Valency* is, in fact, *the gaseous volume combining ratio* of hydrogen to other elements, although extended by indirect calculations to those elements whose actual gaseous volume cannot be directly measured. The *atomic* weight is the weight of a unit volume of the elements in the gaseous condition, compared to that of hydrogen as unity.

284. As modern science accepts the doctrine that heat is a "mode of motion," and as motion implies space to move in, it is obvious that there must be a relation between heat and the space occupied by the moving particles; heat being only one form of energy, we readily extend this relation to energy in all its forms, and therefore, although we are not yet far enough advanced in actual knowledge to define all the facts and laws, we can see very clearly that there is in nature an exact relation among the weights of the atoms of matter, the spaces they move in, and the energy they absorb, that is to say, between the atomic weights, molecular volumes, and intrinsic energies of substances. We can see in fact that if, by the agency of energy, atoms are made to occupy a different space from that common to them, they must have new properties; especially as there is an evident relation between this space and the powers of atoms to combine; that is to say, under these altered conditions of energy, the *valency* (which is a function of volume and energy) will be altered; as a consequence we can conceive of the existence of two or several compound substances containing the same elements and in exactly the same proportions, but owing to differences of intrinsic energy having very different chemical properties, and belonging to entirely different molecular types. This may explain "isomerism" (equal measures of the same elements in different compounds); it also explains "allotropy" (different forms of the same substance), as due to different specific energies forming part of the molecules, attended probably with a different number of atoms entering into the molecules, which have consequently different physical properties. Carbon, sulphur, and phosphorus are well-known substances taking different forms, and ozone O_3 is a modified molecule of oxygen.

285. Berzelius's electro-chemical theory (§ 252, p. 210), which long ruled chemistry, assumed that each element possessed, as part of its constitution, a definite quantity of positive or negative electricity, which set up the chemical attractions between them; that they united into acid and basic radicals, the attractions of which

for each other were due to the excess of + or − electricity not neutralized in the primary act of combination: he therefore drew up a list of electro-negative and electro-positive substances. It will be seen, therefore, that on this view each kind of molecule possessed *different quantities of electricity*, which are the causes of the varying degrees of affinity. But Faraday distinctly proved that there is a relation based upon the equivalent constitution of matter. Thus, if a cell is set up, based upon zinc displacing silver from its nitrate, a definite quantitative result will be effected by the current; if passed into a copper solution, it will reduce a definite quantity of copper, and the quantity will be in the ratio of the old equivalents of the metals—i. e. for 108 grains of silver precipitated in the battery, 31·75 will be deposited in the cell. But copper will precipitate silver, though with much less force than zinc does, therefore it is said that a much lower affinity is at work; if, then, copper is used for a battery with a silver salt, a current will be set up, and this current also will, for the 108 grains of silver in the battery, deposit 31·75 of copper in the cell. Again, iron will throw down the copper, and zinc the iron; in each case a lower affinity at work in the battery produces exactly equal reduction in the cell, though taking a longer time to effect it. But, again, if we place in a series, cells containing different classes of molecules, and pass a current through all—such as salts of silver, copper, and iron—the same current passes through them, and deposits in each cell its metal in the order of its equivalent, 108 silver, 31·75 copper, 28 iron, for each 32·6 of zinc dissolved in a cell of the battery. Therefore Faraday said that every molecule, no matter what its nature or what the chemical affinity within it, requires or gives up the *same quantity of electricity*, and this is law IV. (§ 282).

286. How shall we reconcile these two conflicting views, for both of them are based on truths? Careful consideration of the facts will show us that Berzelius based his ideas upon the conditions set up by "intrinsic energy," while Faraday's law is based upon the "valency" of atoms and radicals, and consequently upon the construction of molecules.

When we see that electricity is a something wholly dependent on the molecular constitution of matter, that it can be transmitted or measured only by motions of the molecules, and those motions transmitted along a definite chain by the action of one molecule upon another, it is easy to see that there must be a relation dependent upon the *number* of molecules moved or broken up, which relation we may, if we please, call a *quantity* or an *equivalent* of electricity, and so take possession of Faraday's labours.

When we learn that energy is an integral part of the molecules of matter; that the component atoms are moving at definite rates, as the spectroscope shows, and that chemical combination is attended with a reduction of that motion, and its release as external heat, or as motion along a line of polarized molecules in electricity, we see why each such action must give up a definite amount of energy, and why, according to its amount, the molecular motion it sets up (the "quantity") shall be slow or rapid, and therefore the tension set up upon the molecular chain shall be great or small in the ratio of the chemical affinities at work. Here, then, we take possession of Berzelius's labours, and connect the two conflicting theories into a more general conception.

287. What is the quantitative relation between electricity and matter? Is it molecular or atomic? Is it dependent on the atomic weight of the modern chemical notation? or is it, as nine people out of ten suppose, dependent upon the old equivalent weights? Upon none of these, and yet upon all of them. Our knowledge is, in fact, not yet sufficiently advanced to enable us to give a definite explanation of the mode of relation between electricity and the molecular constitution of matter. In Table XIII. (p. 212) is given a list of the actual quantitative relations; and a little examination of some of the relations of matter and energy may throw some new light both upon the cause of these relations and upon the chemical constitution of substances.

The elements combine with each other in exact definitive ratios, and those ratios, as was stated above, have a twofold aspect: (1) the *weight* of matter involved; (2) the *measures* in the gaseous states. The atomic weights now adopted (Col. III. of Table XIII.) combine both these aspects: they are the weights of those measures which equal in volume one weight of hydrogen. Some substances cannot be so measured, and the figure is arrived at indirectly; some, again, are experimentally exceptions; they may be half or double measures when actually compared as elements, and yet when entering compounds they agree with the accepted figures. This requires explanation: why is a law to be accepted as universal when experiment shows us there are exceptions? Experiment is the foundation of all knowledge, but the deductions from experiment must be broad; they must be based upon the *spirit* not upon the *letter* of the replies which Nature gives to our questions. When several different experiments appear at first to differ in their teachings, it is our duty to see if we cannot find some broader road to knowledge of which these are several bye-ways. The relations of energy to matter vary in different physical states, and in the one physical state of gas they vary according as we recede from the point at which the gas becomes a liquid, that which is commonly called the boiling point. Yet through all these variations we see a fundamental law of Nature (the law of Boyle and Mariotte, Dulong and Petit); the relation of energy to matter as gas is definite—equal heats, equal pressures, produce equal expansion and contraction. The variations are due to the imperfect gaseous condition (as shown, p. 147), and our inability to compare all bodies at the proper point at which Nature fixes that relation; therefore in our experiments we employ part of the energy we use in carrying out some other kind of relation as well as the particular one we wish to examine. The remedy is, to arrive as far as possible at the knowledge which each experiment gives in one direction, and then to accept the general teachings to be derived from many.

It is upon this principle that we may regard the accepted atomic weights as representing the abstract unit gas volumes of the several atoms, and two such unit *atomic* volumes as the unit *molecular* volume, into which Nature compresses all the atoms of which she builds up every molecule of known substances. But these atoms do not combine in mere pairs. One volume or atom is *equivalent* to, or can combine with or replace, one, two, three, or more atoms or unit volumes of other elements; yet when so combined—no matter how many volumes enter into union—they condense down to *two* volumes, as shown § 283. This is so universal that we are bound by the principles of honest reasoning to recognize that the apparent exceptions are due to the different conditions of energy to which we are compelled to expose, in order to compare, them. Taking, then, the unit volume of hydrogen, the lightest substance and the most perfect gas (therefore the simplest known substance in its relation to energy), as our base, we class atoms as equivalent to one, two, three, four, &c., atoms of hydrogen, and call this relation the valency of the atoms. Some substances are capable of possessing several different valencies; thus copper, a bivalent atom, unites with chlorine, a univalent element, as $CuCl_2$; but it also unites with it as Cu_2Cl_2. We know that each atom is not mere matter; energy is also part of its essence; the atom is a vibrating body, and the space it occupies—its unit volume—depends on this motion; we have, then, the right to conclude that copper can part with some of this intrinsic energy, that two ordinary atoms can condense into one, and will then represent matter and energy constituting one atom, occupying one abstract unit gas volume, and having, in its relations to other atoms and to energy, the value of one atom only (and all those properties, chemical and physical, which Nature has connected with the unit or atomic gaseous volume), but capable of again absorbing energy, and so reconstituting two atoms.

Now energy, in the form of electricity, is related to the atoms and molecules in a manner which links together these other relations. This relation can be formulated as,

$$\frac{\text{Atomic weight}}{\text{Valency}} = \text{electric equivalent.}$$

We can therefore give to Faraday's "quantity," or "equivalent of electricity," a definite value accordant with the chemical constitution of matter; it is that action which will release one univalent atom or radical, elementary or compound; that is to say, it passes along one of the links by which molecules are constituted, as represented in Fig. 40, p. 85; in so doing it acts upon and, in chemical action, releases the unit radical, and exerts a definite magnetic action externally by means of the inductive conditions it sets up in surrounding bodies. To define its electrolytic action still more strictly, it will release one univalent *radical*, which radical may be a single atom, or may be built up of many atoms of any valency brought into that state which corresponds physically and in its relation to energy with the unit gas volume and single valency. This unit of electricity, measured on a grain system, is that used in this work, viz. the equivalent of one grain of hydrogen. Each molecule, therefore, acts in the electric circuit as though it were so many molecules as would represent the "valency" of the two radicals or ions into which it breaks up. How or why this relation exists our present knowledge does not enable us to explain, but that this is the true relation of electricity to matter is certain, for this law covers all the known facts, all the exceptions to the common accepted laws of electrolysis (§ 282); but we can see that it is probably connected with the unit atomic gaseous relation of matter and energy, extended into all other physical conditions.

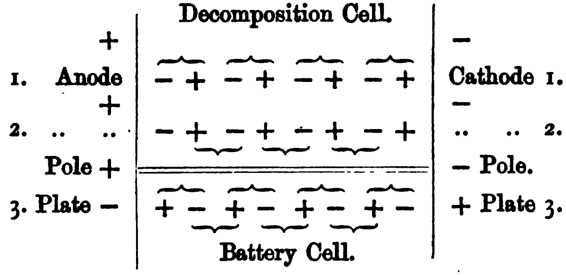
288. But electrolytes have another relation to electricity besides that of current equivalent. A true electrolyte, setting free its two radicals, requires a definite force exerted upon it, variable, not as before, by classes, but with every single substance according to the strength of what is called the chemical affinity of the two ions.

If we set up a battery and a certain resistance, a given current will pass; extra resistance will diminish the current, but no amount of resistance will quite stop it: an amount $\frac{E}{R} = C$ will always pass. If we set up a battery which will just pass current through a solution of iodide of potassium, and then substitute for this, dilute sulphuric acid, no electrolytic current will pass at all; the decomposition cell is not a mere resistance, but as soon as it is polarized it is a *counter electromotive force* (§ 236), and is expressed in formulæ as $-e$. This is, in fact, only an illustration of the fundamental law of Nature that action and reaction are always equal. If we pull on a rope fixed to a post, the post resists us, and the strain on the rope at the post exactly equals that at the other end; spring balances at the two points would show the same pull in opposite directions. So when chemical affinity is exerted in combination, it sets up an E M F in one direction, a tension on the polar chain; if decomposition occurs, the radicals set free absorb an equivalent energy, and act as an E M F in the opposite polar direction, that is, as a − E M F. Therefore it is that to effect decomposition against any chemical affinity, the E M F exerted must be somewhat greater than the − E M F set up, or no action can occur at all; upon the degree of excess will depend the rate of action. To ascertain, therefore, the amount of electrolysis which can be effected by any battery, and under any conditions of resistance, the formula is $\frac{E - e}{R} = C$.

If E and e are expressed in volts, according to the system explained, §§ 253 to 256, R being the total resistance, metallic and liquid of the circuit, C will be a figure which, multiplied by 5·68 to bring it to "chemics," and by the proper figure in Col. VI., Table XIII., p. 212, will give the actual weight in grains set free in ten hours' action.

289. There are, however, two ways of looking at the action which goes on in a decomposition cell forming part of an electric circuit. (1) We may regard the solution as a *conductor*, transmitting current exactly in proportion to its resistance. (2) We may regard the solution as a *dielectric*, and the electrodes as condenser plates which we can charge up to a certain tension at which the dielectric breaks down. Each of these views is true, and it is only by combining them that we can obtain a complete conception of the conditions. Treating the cell as a condenser, we may, in fact, see in it the conditions of static charge explained §§ 36 to 40, and the electrodes correspond to the plates in Fig. 26, p. 50; or regarding the anode as a surface taking a + charge, we get fresh light upon the conditions illustrated, Fig. 13, p. 30. In fact, we give the electrodes a charge, the tension of which will depend upon (1) the electromotive force of the battery; (2) the inductive capacity of the interposed liquid; (3) the relation the resistance of the cell bears to the total resistance of the circuit. This view holds good for all liquids (as also for all substances whatever), electrolytes or not.

But, in a condenser, the dielectric, though it does not transmit current, or only slowly, is polarized statically in the same direction as though currents were passing, and each charge, each act of polarization that is, absorbs so much energy as the inductive capacity can take up, and necessitates a proportional consumption in the battery; that is, each molecular chain to be polarized requires a molecule of action in the battery, and will consequently show a corresponding current (or molecular revolution) in the connecting wires, &c. We may, therefore, picture the conditions thus—



The first line shows the static conditions as a condenser; the second, the result of electrolysis; and the third, the polar condition of the battery. We see here that, regarding the battery as the source of energy, it polarizes the contents of the cell (1 and 2), and so completes a circuit; but, looking at the cell itself as a reacting source of tension or electromotive force, we see that *in either case* the cell produces a tension in a direction opposite to that of the battery itself, and the diagram shows us why, (1) as a condenser, by giving up the energy stored up as charge, by the strain upon the brackets or molecular affinities, which act like strained springs, or any other mechanical reaction which absorbs and then gives up energy; (2) by the tendency to reunion of the freed ions, which act upon each other through the liquid just as they do in a battery when an acid and alkali are separated by a porous division, § 164, p. 116. Either of these actions will tend to make the anode positive, as will be seen by the order of the symbols + and −; as the battery does the same, the effect is that of two cells in multiple arc or "coupled for quantity;" and all the actions tend to convert the prolongation upwards of the electrodes into + and − poles. The battery and decomposition cell are, therefore, identical in principle with two cells with similar poles opposed, and no current can pass unless the electro-motive force of the one cell (the battery) exceeds that of the other cell (the electrolyte).

290. POLARIZATION OF PLATES.—This is the very confusing name given to the E M F just described. It is occasionally employed practically, in order to obtain a short current of great force from a feeble battery. Lead plates may be immersed in

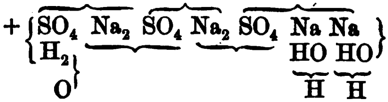
dilute acid, or any suitable agents may be employed with a battery just powerful enough to set up the reaction. A number of the decomposition cells are used with a commutator which arranges them in multiple arc, and puts them in circuit with the battery, which then charges them as a condenser of large surface; the commutator then throws the whole into series, producing a battery of great E M F, which gives off a current, great at first, but rapidly falling, which is, in fact, the charge of the condenser given up in another form. Such currents last only while this charge is given up, or while the freed ions, if there are any, recombine; and therefore, however great they may be at first, they diminish rapidly and last but a very short time.

291. The electrodes of a cell are not necessarily metals. When two liquids are separated by a porous diaphragm, the surfaces of the liquids in contact act as electrodes to each other, and the precipitation may occur there just as happens at a plate. A series of liquids may be connected in this manner, and current passed through the whole. The examination of what happens in this case will clear away many very common misconceptions. Thus, it is often said that "ions can be transmitted through materials for which they have a strong chemical affinity without combining with them." Now this is not the case. No ion can be so transmitted. The illustration usually employed represents three connected liquids—sulphate of soda, infusion of litmus, and water. After a time sulphuric acid is found in the water, and it is considered that it must have passed through the litmus solution, yet it has not coloured it. But what has occurred is quite different. Not sulphuric acid, but neutral sulphate of soda, has traversed the solution, by simple endosmose. Until this endosmose has brought some of the salt over no acid would be released, nor would any current pass at all unless some saline substances were in the water. But if in any intermediate solution there is a chemical affinity for one of the ions, capable of producing a precipitate, that ion will never pass across the solution. Suppose there are four solutions, common salt at the cathode, sulphate of soda next, then nitrate of silver, and again sulphate of soda—no particle of chlorine would ever find its way to the anode, but sulphuric acid would be set free there; any chlorine which either by endosmose or by electrolytic transfer reached the silver cell would there be at once precipitated. What really occurs is a constant interchange of the ions between contiguous molecules along the polar chain, so that when this is composed of different electrolytes in contact, the different constituent ions are soon distributed; but whenever in the course of this distribution two ions come together which have a mutual affinity great enough to cause an ordinary chemical combination,

they become insoluble, and drop out of the polar chain. Faraday proved this by decomposing sulphate of magnesia in contact with water in strata one above the other, and with precautions to prevent disturbance by gas: no magnesium found its way to the cathode, but on entering the water it formed a film of magnesia in the middle of the liquids at the line of junction, which served as electrodes to the separated liquids.

292. To understand the chemical actions effected by the current, it is necessary to examine them first in a pure electrolyte, a single substance: and most of these have to be liquefied by fusion. A good example is chloride of silver with silver electrodes: the silver adheres to the cathode and the anode dissolves away, maintaining the chloride of silver constant. This is *Direct* Electrolysis. With a very large number of substances in *solution*, a different kind of action occurs, which is called *Secondary* Electrolysis. I will give the usual explanation of this first, and then show a principle which explains it more perfectly and in better accord with the principles of the electric current.

293. If we electrolyze a solution of sodium chloride NaCl, we obtain Cl at the anode; at the cathode we do not obtain Na, but we have instead of it H, hydrogen, in the proper equivalent proportion; in the solution we have an equivalent also of caustic soda NaHO. But if we electrolyze sodium sulphate Na_2SO_4, we obtain at the anode an equivalent of oxygen O, and also an equivalent of free sulphuric acid H_2SO_4, while at the cathode we have the same as in the case of the chloride; we have, therefore, in this case apparently two equivalents of substances set free for one equivalent of current. The explanation given is this: if we add sodium, Na, to water, we decompose the water, we produce NaHO caustic soda, and H as free hydrogen. Therefore, when we decompose NaCl, we actually set free Na in presence of water, which is then decomposed by *secondary* or purely chemical action. In the case of the sulphate we also set free at the anode (or render nascent) SO_4 a radical which cannot exist separately, but which likewise acts upon water, H_2O, forms H_2SO_4, and sets free O, oxygen, also by a secondary chemical action. We may picture the reaction thus:



$$+\left\{\begin{array}{l}\overbrace{SO_4\ Na_2}\ \overbrace{SO_4\ Na_2}\ \overbrace{SO_4\ Na\ Na}\\ \left.\begin{array}{l}H_2\\ O\end{array}\right\}\quad \underbrace{Na_2\ SO_4}\ \underbrace{Na_2\ SO_4}\quad \underbrace{HO}_{H}\ \underbrace{HO}_{H}\end{array}\right\}$$

The upper row of brackets show the original molecules of Na_2SO_4, of which the end ones break up and react upon the water, which does not enter the polar electric chain. If this explanation were true, the E M F required would be that of composition of Na_2SO_4, and that is:

NaO by Table XIII.	14593	foot-pounds
NaO + SO_3, by Table XIV.	3139	
	4673) 17732 = volts 3·8	

There would also be heat produced in the liquid equal to that of the action of sodium on water. Now we know that an E M F of 1·5 volts is sufficient to just set up the action, and that this heat is not generated. To understand what really occurs, and so get rid of the complication of direct and secondary electrolysis, we must distinguish between the actions in the body of the *liquid*, and those which occur *at the electrodes.*

294. *The action in the body of the liquid* consists of molecular motions transmitting the current, and the interchange of ions among themselves as they happen to meet with others capable of combining with them. These actions are entirely of the nature of *resistance:* the current, therefore, will divide itself among any number of mixed electrolytes as among different wires, in the order of their resistance; therefore, in an ordinary coppering solution containing a good deal of free acid, the current will be carried mainly by the acid, because the conductivity of sulphuric acid 1 to 11 of water is 89, compared with sulphate of copper as 5.

295. *At the electrodes there is a selective power.*—This is not based on resistance, but solely upon the ratios of electromotive force required to furnish the requisite energy. If several anions are in contact with the anode, that one will be set free whose specific energy is lowest; hence in dilute hydrochloric acid, &c., chlorine is selected because its energy with hydrogen is only 4721 foot-pounds, while the other anion present, oxygen, requires 6841 foot-pounds. (See Table XIII., p. 212.) If the anode is soluble, that anion would be selected whose specific energy is highest when combining with the anode, as then it would contribute energy to the polar circuit as + E M F (both these statements are subject to limits which will be considered presently). At the cathode a similar selective action occurs: thus, if a copper solution contains iron, copper only will be reduced, because the – E M F of copper is only 1·26 volts (Table XV., p. 214), while that of iron is 2·07; for this reason also hydrogen is not released in presence of metallic salts, except when their specific energy, or – E M F, approaches nearly to that of hydrogen. Hence in depositing nickel or iron, hydrogen is always given off, despite of Smee's law to the contrary. The principles I am laying down show

us why. The − E M F of iron is 2·07, and that of hydrogen is only 1·9, nearly the same.

296. It is probable that there are cases, however, in which a true *secondary* or *chemical* reaction occurs. Such are those actions in which no direct *ion* is released from a broken-up molecule; but a complete molecule has a part of its constituents removed or substituted, or extra atoms (forming the true ion released) are added to it. Such an action occurs at the cathode when nitric acid is present there; the *nascent* hydrogen reacts upon it in manners varying with the rate of current and the concentration of the acid; if this is weak, hydrogen is given off. In other cases the acid is reduced more or less by the hydrogen removing one or more atoms of oxygen; if the action is strong, a part of the acid HNO_3 is even wholly reduced, the oxygen is substituted by hydrogen, and the radical ammonium is formed, which unites with another atom of acid to form nitrate, thus:

$$\begin{matrix}HNO_3\\HNO_3\end{matrix} + H_8 = NH_4\,NO_3 + 3H_2O.$$

A corresponding action may occur at the anode by the power of *nascent* oxygen or chlorine. On this account it is dangerous to electrolyze a strong solution of sal ammoniac (ammonium chloride); and I select this example because it is an experiment very likely to be made; it decomposes into ammonium NH_4, which breaks up into $NH_3 + H$ at the cathode, and Cl at the anode, and the chlorine partially reacts upon the salt and forms drops of chloride of nitrogen, a violent and unmanageable explosive: thus $NH_4Cl + 6Cl = 4HCl + NCl_3$. I give this formula for simplicity sake, but no one knows what chloride of nitrogen is. Some consider that it is really HCl_2N, Cl_3N, but its analysis presents no great inducements and a great many difficulties. But while these actions, which are producible by ordinary chemical reactions, may be regarded as secondary actions of substances set free, it is more likely (and more in accord with the general facts) that, in most cases, the molecules reacting are actually ranged in the polar electric circuit, and that the actions are effected under the influences exerted by the current. We may therefore substitute for the confusing ideas of direct and secondary action the following new definition, which will embrace all the facts.

297. GENERAL LAW OF ELECTROLYSIS.—*At the electrodes those substances are set free which absorb, in becoming free, the lowest specific energy.*

That is to say, at the point where the current enters or leaves the electrolyte, any neighbouring molecule, *whether an electrolyte or not*, will be ranged *in the polar circuit*, provided, either that one part of it can unite with the true *ion* turned towards the electrode and the other part can form a free molecule, absorbing from the circuit less energy than the *ion* of the true electrolyte would require in order to become free, or that the true ion can be introduced into this other molecule at a less expense of energy than would be needed to enable it to constitute a free molecule. The substances set free may be thus formed afresh out of materials in contact at the electrodes, not merely separated as ions or radicals from previously existing molecules, although this latter is the fundamental type and general action of electrolysis.

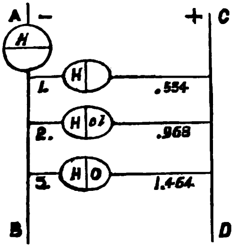
This new conception, it will be seen, establishes an analogy between the effects of electricity in electrolysis, and those of heat in destructive distillation. As in this last case the substances arrange themselves in new forms suited to the forces existing in the retorts as degrees of temperature, so in the decomposition cell they arrange themselves in forms suited to the forces existing as degrees of electric tension or electromotive force.

298. Mixed Electrolytes.—In § 238, p. 196, it is shown that when several paths are open to the current, it divides itself among them all in the inverse ratios of their several resistances. Every conductor is, in fact, a system of such "derived circuits," as the unit conductor is the single chain of univalent molecules. Fig. 63, p. 193, shows that in liquids every part is polarized, and forms a system of derived circuits, of unequal resistance, from every part of one electrode to every part of the other electrode, and as a consequence every part of the liquid in the cell carries a part of the current proportioned to the lines of resistance in which it enters; but this relates only to the true resistance to conduction, § 236. The conditions are quite different when the different "derived circuits," or paths for current, are different electrolytes; those conditions will also be very different when the electrolytes are in different cells, and when they are mixed in one vessel.

As a consequence of the balancing of electromotive forces, when a current enters a mixture of electrolytes and passes along them in the ratio of the resistances, it also decomposes them in the order of their electromotive forces. We have seen, § 289, that it will act on none whose $-$EMF exceeds the tension to which the electrodes can be raised; yet it may do so apparently. It may at one electrode select one ion alone, and at the other either an ion, originally forming part of the same, or of a different electrolyte; or it may release several and redistribute the other constituents. It will release, first, at each electrode, *such ions as take up least energy*, whether they originally formed part of the same electrolyte or not. If the tension is raised much beyond the point needed for his, ions requiring more energy will be released, in ratios dependent largely upon the quantities present, and in contact with the electrodes.

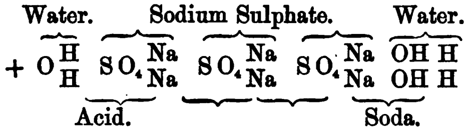
299. Electrolytes in derived Circuits.—If, instead of going through a mixture of several electrolytes, the circuit is divided into several branches, or derived circuits, with a decomposition cell in each branch, containing electrolytes of different – E M Forces, then a different set of conditions will arise. The result will be governed by the laws of derived circuits, but with modifications due to the presence of these varying opposing electromotive forces. Let Fig. 69 represent three such derived circuits (1) containing sulphuric acid with a copper anode, with a – E M F = ·534; (2) Hydrochloric acid which gives off HCl, the force of union of which being 4523 ft.-lb. = ·968; (3) Sulphuric acid with platinum electrodes – E M F = 1·464. If these figures were resistances, the common current would divide itself between the lines in the opposite ratio, and if each were measured, and the common current were measured also in A, the sum of 1, 2, 3 would be equal to that of A. This latter holds good in any case; if A is a voltameter or a Smee cell, it will give as much hydrogen as 1, 2, and 3 together; but the ratios between these latter will be quite another matter. Until the difference of tension between A B and C D rises to ·534, no current would pass; then it would go wholly by 1; when it rose beyond ·968 a little would go by 2, but only a small proportion; and it would require greater battery power than if 2 were acted upon alone, because by the laws of derived circuits, the tension would be equal at all the junctions of 1, 2, 3, with A B, and, therefore, the facility of passage opened through 1, would rapidly lower the tension in the common conductors, and make it more difficult to raise it to the degree necessary to pass any current through 2 than it would be were 1 disconnected.

Fig. 69.



300. Electrolytic Reactions.—We may now apply these theoretical principles to actual cells in which well-known reactions are carried on.

(1) The decomposition of sodium sulphate, instead of taking place by "secondary" action as shown in § 293, p. 254, is effected by molecules of water entering the polar chain itself; the extreme ions of the chain go off as gases, and the formula becomes

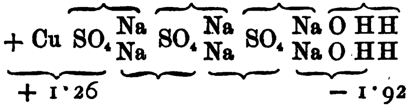


$$\begin{array}{c} \text{Water.} \qquad \text{Sodium Sulphate.} \qquad \text{Water.} \\ +\ \mathrm{O}\begin{matrix}\mathrm{H}\\ \mathrm{H}\end{matrix}\ \mathrm{SO_4}\begin{matrix}\mathrm{Na}\\ \mathrm{Na}\end{matrix}\ \mathrm{SO_4}\begin{matrix}\mathrm{Na}\\ \mathrm{Na}\end{matrix}\ \mathrm{SO_4}\begin{matrix}\mathrm{Na}\\ \mathrm{Na}\end{matrix}\ \begin{matrix}\mathrm{OH\ H}\\ \mathrm{OH\ H}\end{matrix} \\ \text{Acid.} \qquad\qquad\qquad\qquad \text{Soda.} \end{array}$$

The upper brackets show the original molecules, and the lower ones the result of the action; and I have individualized the atoms in order to show why a bibasic salt, such as a sulphate, takes two equivalents of current to decompose it, the equivalent being based on 1H.

This reaction requires 1·5 equivolts of energy to effect—that is, so much energy must be given up by the current, in order to set oxygen and hydrogen free, and the cell will act as a $-e$ of that force.

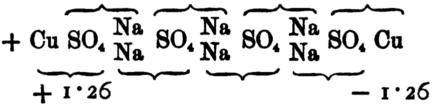
(2) But the anode represents the zinc of a battery cell, and if it can combine with any anion or acid radical present it dissolves like the zinc, and like it gives a + energy to the circuit. If therefore the anode is made of copper, current would pass with less expenditure, and the action would become



$$\begin{array}{c} +\ \mathrm{Cu}\ \mathrm{SO_4}\begin{matrix}\mathrm{Na}\\ \mathrm{Na}\end{matrix}\ \mathrm{SO_4}\begin{matrix}\mathrm{Na}\\ \mathrm{Na}\end{matrix}\ \mathrm{SO_4}\begin{matrix}\mathrm{Na}\\ \mathrm{Na}\end{matrix}\begin{matrix}\mathrm{O\ HH}\\ \mathrm{O\ HH}\end{matrix} \\ +\ 1{\cdot}26 \qquad\qquad\qquad\qquad -\ 1{\cdot}92 \end{array}$$

Here we see that the energy absorbed is 1·92 − 1·26, or only 0·66 of an equivolt, because at the anode a reaction occurs which gives up energy; or, more simply, there is only absorption at the cathode for setting hydrogen free.

(3) We may have at the cathode also, an ion present which requires no more energy to set it free than a corresponding reverse action at the anode will supply, then we have an electrolysis which is only a resistance, not a − electromotive force, and which therefore the very feeblest force can accomplish. If we place copper sulphate at the cathode of the last reaction, it becomes



$$\begin{array}{c} +\ \mathrm{Cu}\ \mathrm{SO_4}\begin{matrix}\mathrm{Na}\\ \mathrm{Na}\end{matrix}\ \mathrm{SO_4}\begin{matrix}\mathrm{Na}\\ \mathrm{Na}\end{matrix}\ \mathrm{SO_4}\begin{matrix}\mathrm{Na}\\ \mathrm{Na}\end{matrix}\ \mathrm{SO_4}\ \mathrm{Cu} \\ +\ 1{\cdot}26 \qquad\qquad\qquad\qquad -\ 1{\cdot}26 \end{array}$$

This is an ordinary coppering reaction, in which, to keep up the analogy, I have used the soda sulphate in the circuit, instead of copper sulphate or sulphuric acid as usual. The copper, in combining with the acid, gives up 1·26 equivolts of energy, as + E M F, and the final act of decomposition absorbs the same as − E M F, leaving only the resistance of the cell to overcome.

(4) In the ordinary voltameter with dilute acid we have a reaction which it will be seen resembles the decomposition of sodium sulphate (1), but the hydrogen comes off at the cathode without producing any other substance there, because the acid itself supplies the hydrogen.

$$\begin{array}{c}\text{Anode}\ \overbrace{}\ \overbrace{}\ \overbrace{}\ \text{Cathode}\\ +\ O\underbrace{H_2\ SO_4}\ \underbrace{H_2\ SO_4}\ H_2\ -\\ \text{E M F} - 1\cdot464\end{array}$$

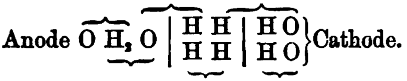
giving, besides the resistance of the cell, a − E M F of 1·464 volts; so that a single Daniell cell of volts 1·079 cannot pass current at all through this cell; but if we use as in (2) a copper anode, which gives a + E M F ·93, so reducing the − E M F to ·534, current passes freely, hydrogen is given off, and sulphate of copper formed. It will be observed that in formula (2) the corresponding reaction shows a force of 0·66, while here it is ·534, although in both cases the same products are set free. The figures are arrived at by different processes, the data for which are as has been explained, p. 208, very uncertain. Besides this, the presence of the caustic soda in the first case introduces an element which does not exist in the other, and this is the real cause of the greater force required. All these figures are given, however, to illustrate principles as yet understood by very few, not as actually accurate in themselves.

301. WATER NOT AN ELECTROLYTE.—Almost all the books give diagrams, and speak of the decomposition of water; in fact, they commonly attribute the processes of electro-metallurgy to secondary action of the hydrogen set free by the decomposition of water; they speak also of water being a bad conductor, but made better by the presence of acids and salts. The foregoing principles enable us to define *a true electrolyte as a pair of ions which will break up under a tension equivalent to the* affinity which holds them together. It is doubtful whether pure water is not one of the strongest insulators; at all events, it will not only not electrolyze under a tension of 1·5 volts, but it resists a hundred times that tension: therefore it is not an electrolyte. This point has been often argued. Some have said that alternating currents will decompose water, only the constituents reunite at the electrodes; this plan is obviously merely reversing the charges of a condenser, swinging the water molecules backwards and forwards, not breaking them up, nor passing current through the water at all. Others have tried to diminish the resistance by coiling up two platinum plates separated by silk, giving great area and little thickness of liquid. They passed current,

and got gases unquestionably, but it is scarcely necessary to say that it was not *water* which was being decomposed. The fact is, really pure water is unknown, even to chemists; it cannot be made, and, if made, could not be kept five minutes. Water is a close approach to the long-sought object of the old alchemists—a universal solvent. The purest platinum, even though made red hot, &c., is sure to have *some* residuary impurities or adherent gas, and thus the conditions of ideal electrolysis are inevitably vitiated.

302. Water and many other substances permit a slight current to pass without undergoing electrolysis; and it has been argued that this is caused by the gases being given off and absorbed by the liquid. We cannot limit nature, nor can we be quite sure that liquids cannot conduct, in some degree, like metals and solids, as even guttapercha does. But there is another point to consider. Water freely dissolves air, and takes up the oxygen in a higher ratio than the nitrogen: it is by this property that fishes are enabled to breathe; therefore when the water is polarized as a dielectric, and its hydrogen tends to escape, it finds itself always in presence of a small quantity of oxygen, and that, also, in all probability condensed upon the platinum which possesses the property of so condensing gases; besides this, platinum and also gold will unite with both oxygen and hydrogen in some small degree, and it is highly probable that the small current (very slight it is) which is known to pass is really due to these various agencies which set up a + E M F, sufficient to enable even a small tension to pass a current proportioned to it and the resistance.

303. In the various reactions commonly called the decomposition of water, the oxygen and hydrogen gases do not come off pure, and consequently the exact theoretical measures are rarely obtained. Ozone is generated at the anode, and peroxide of hydrogen at the cathode. These are both remarkable substances, as possessing the contradictory properties of being both oxidizing and reducing agents. Ozone is a molecule of oxygen containing three atoms instead of two, and with the third molecule ready to leave at the earliest opportunity; therefore it will take oxygen from an oxidizing agent to form ordinary oxygen, and hydrogen from a reducing agent to form water. The reaction which produces them may be written thus:



$$\text{Anode}\ \overbrace{O\,H_2}\!\!\!\!\!\!\underbrace{\,O}\ \overbrace{\Big|\ \underbrace{\begin{matrix}H\ H\\ H\ H\end{matrix}}\ }\ \overbrace{\Big|\ \underbrace{\begin{matrix}H\,O\\ H\,O\end{matrix}}}\Big\}\ \text{Cathode.}$$

An atom of oxygen released at the anode, and its two atoms of hydrogen acting on two molecules of water, so as to form two molecules of free hydrogen and one of hydrogen peroxide H_2O_2.

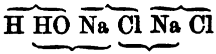
Three such reactions give three atoms of oxygen to form a molecule of ozone O_3 at the anode.

Nearly pure water containing air, when electrolyzed by a powerful current, generates nitric acid HNO_3 at the anode, by nitrogen and water taking up oxygen, and ammonia at the cathode by direct union of nitrogen and hydrogen, thus:

$$\text{Anode}\ \left.\begin{array}{r}2N\\5O\\H_2O\end{array}\right\} = 2HNO_3 \qquad \text{Cathode}\ \left.\begin{array}{r}2N\\10H\end{array}\right\} = 2NH_3 + 4H$$

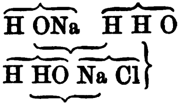
304. **Dissociation.**—When a current from a frictional machine enters water by means of fine points, decomposition occurs; it is not, however, *electrolysis*, but *dissociation*; both gases are given off together at each of the electrodes; this is due to the high tensions set up and the violence of the vibrations produced, analogous to the action of a flash of lightning, so that the atoms of O and H constituting water are, as it were, shaken apart. Similar dissociation is produced chemically in water (as steam), and in many substances when the temperature or heat tension rises beyond the degree at which combination occurs. This fact has a striking analogy to the disruptive action exerted in electrolysis when the tension rises beyond the chemical affinities of the radicals, both expressed in the equivolt unit.

305. In the electrolysis of common salt NaCl, for every unit of current one atom of hydrogen will be released at the anode throughout the action; but none of the other reactions will be uniform: at first the action accords with the ordinary laws, and for each atom of hydrogen there will be an equivalent of sodium hydrate at the cathode, and of chlorine at the anode.



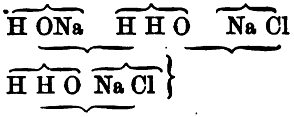
$$\overbrace{H\ HO}\ \overbrace{Na\ Cl}\ \overbrace{Na\ Cl}$$

But, as the caustic soda accumulates, it carries a part of the current, and then commences a series of complicated actions at the anode. Chlorine is no longer given off alone, but some oxygen accompanies it by the following process, part of the Cl taking up H and forming HCl:



$$\begin{array}{l}\overbrace{H\ ONa}\ \ \overbrace{H\ H\ O}\\ \overbrace{H\ HO}\ \overbrace{Na\ Cl}\end{array}$$

The same reaction also extends itself by taking up a molecule of the salt, and forming sodium hypochlorite, instead of setting the oxygen free.



$$\overbrace{\mathrm{H\;ONa}}\quad\overbrace{\mathrm{H\,H\,O}}\quad\overbrace{\mathrm{Na\,Cl}}$$

$$\left.\overbrace{\mathrm{H\,H\,O}}\;\overbrace{\mathrm{Na\,Cl}}\right\}$$

In consequence of this and similar reactions, chlorates and other oxygen salts may be formed at the anode when chlorides are electrolyzed, instead of the full equivalent of chlorine being given off. In the electrolysis of hydrochloric acid similar results occur, and oxygen is set free as well as chlorine, and the ratio of oxygen increases as the acid is weaker, because there are more oxygen atoms in the vicinity of the electrode.

These and many similar little-studied reactions have a deep significance hitherto overlooked. They have been commonly dismissed as slight exceptions from the established laws of electrolysis, or as incidental results of "secondary" action. They really show that this indirect, chemical, or secondary action is a delusion; dismissing it, we can ascend to that higher and more general law formulated, § 297, p. 256.

306. In electrolysis there is no direct transfer of ions from one electrode to the other, but a constant interchange of radicals in contact, which owing to the selective power exerted at the electrodes tends to the accumulation of two classes of radicals, which in the case of salts in solution would ultimately result in collecting all the acids on one side and all the bases on the other; but this could never be effected as many suppose by a current equivalent only to these products; in practice, also, in an ordinary depositing cell the result of long-sustained action is the transfer of the metal of the anode to the cathode. But the anions or chlorous radicals tend to accumulate most rapidly, and this has important results in electro-metallurgy, because these chlorous radicals act on the anode and surround it with a heavy saturated solution; while the removal of the metal at the cathode tends to produce a weak and acid solution there, just where a dense metallic solution is most desirable; in fact, if we use a neutral solution of copper sulphate in a cell with a porous partition, and drive a strong current through, in a little while the anode will be covered with crystals of sulphate of copper formed there, but unable to dissolve, while the solution at the cathode will be exhausted so as to give the metal only as a powder.

The mode of transmission of ions and the way in which the metal of the anode is transferred to the cathode may be represented in the following diagram, in which copper is supposed to be immersed in sulphuric acid:

$$\begin{array}{ll}
1. & \overset{+}{\mathrm{Cu}}\;\overbrace{\mathrm{SO_4H_2}}\;\overbrace{\mathrm{SO_4H_2}}\;\overbrace{\mathrm{SO_4H_2}} \\
2. & \mathrm{Cu\;SO_4Cu\;SO_4H_2\;SO_4H_2} \\
3. & \mathrm{Cu\;SO_4Cu\;SO_4Cu\;SO_4H_2} \\
4. & \underbrace{\mathrm{Cu\;SO_4}}\underbrace{\mathrm{Cu\;SO_4}}\underbrace{\mathrm{Cu\;SO_4}}\mathrm{Cu}
\end{array}$$

The upper brackets show the constitution before action, and the lower ones the result of one action upon each molecular chain; after each action, which involves a redistribution of the radicals, the newly-formed molecules make a semi-revolution so as to renew the polar condition; at each action, therefore, a molecule of copper sulphate is formed by copper entering at the + end, and hydrogen leaving at the cathode, until at length copper sulphate reaches the cathode, and copper can be set free there instead of hydrogen.

307. **Experiments** in electrolysis are very interesting and instructive, and everyone who wishes to understand the subject should make them for himself, taking care as far as possible to watch all the quantitative relations of the current by some of the means described in the chapter on measurement. There have been many complicated and expensive forms of apparatus devised, but the most important experiments can be performed by the very simplest means. Wires of suitable metals serve for electrodes, and small U tubes made by bending up pieces of glass tubing will serve for cells, the two liquids being placed separately in the legs; in some cases it may be well to fill the bend with fine sand; straight lengths of tube, closed at the bottom with a plug of plaster of Paris or asbestos, may be used by dipping them in a vessel of suitable connecting liquid. When gases are to be collected, test-tubes can be used, filled with the liquid, closed with the finger or with a piece of sheet indiarubber, and inverted over the wire electrode. The instrument described, § 269, p. 229, is also admirably suited to electrolytic experiments.

By connecting several such cells or U tubes in series, the student will see that the acids all collect in one arm, and the bases in the other; and by using them singly and noticing the electromotive force or number of battery cells needed to pass any given current, he will make clear to himself the relations of the force and observe the reacting current set up, while the conditions of Fig. 69 can be studied by mounting the tubes side by side or in multiple arc. For instance, let four U tubes contain—1. Solution of potassium iodide with a little starch; 2. Common salt, coloured blue with sulphate of indigo; 3. Ammonium sulphate with infusion of cabbage;

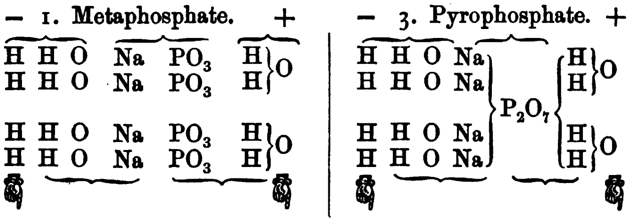
4. Copper sulphate. Connected with platinum wires and placed in series with a strong battery, the anode arms will show acid reactions; 1 will be coloured blue by freed iodine; 2 will be bleached by chlorine; 3 will redden by sulphuric acid; 4 will show acid on litmus paper. The cathode arms will show the presence of the bases: 1 will turn turmeric paper brown by potash; 2 will do the same by soda; 3 will become green by ammonia, or blue if litmus is used in place of cabbage; 4 will deposit copper. Used singly or in multiple arc with gradually increased battery power, they will show the differences in the power required for each of these reactions.

308. In addition to the reactions already described, the salts of phosphoric acid furnish a striking illustration of the relation of electric current to the valency of the ions, and also furnish teachings as to the true constitution of these acids and salts. There are three phosphoric acids:

1.	Metaphosphoric acid	HPO_3
2.	Orthophosphoric (common)	H_3PO_4
3.	Pyrophosphoric	$H_4P_2O_7$

The last two can take up different atoms in substitution of the basic H, or substitute part only, so as to form acid or compound salts.

If we electrolyze sodium salts of each in series, we shall have the same quantity of hydrogen given off by each, and the same quantity of soda generated at the cathode, and equal quantities of oxygen given off at the anode attended with the several acids. Thus we have:



Four units of current (H = 1) decompose four molecules of monobasic metaphosphate of soda in one cell, freeing at the anode four molecules of the acid, containing, of course, four atoms of phosphorus; in the second cell they act upon only one molecule of tetrabasic pyrophosphate of soda, releasing one molecule of the acid, which contains two atoms of phosphorus; yet in each cell the same quantities of oxygen and hydrogen are released, because the same number of water molecules are pressed into the circuit.

309. There are some salts from which oxides are thrown down in a solid form. Such are the nitrates and acetates of lead, manganese, and bismuth, from which the peroxides as PbO_2 MnO_2 are deposited upon the anode. With the lead salts very beautiful effects are produced in this way, as the peroxide in different thicknesses has different colours through which also the metal it is deposited upon may partially appear. By acting on a polished plate with a pointed electrode facing it, rainbow-tinted rings are formed on the same principle as Newton's rings, due to the interference of the waves of light reflected through the film, which diminishes in thickness as its distance from the point increases.

CHAPTER X.

ELECTRO-METALLURGY.

310. Although electro-metallurgy is a purely practical art, and its successful practice may be accomplished with a very small modicum of science, this is true only of the factory; to learn it from books and solitary practice, and in any case to learn it intelligently and to pass beyond the range of mere "rule of thumb," it is necessary to clearly understand the principles in operation, and the terms necessarily employed in explaining those principles, and reference will be made where required to the earlier pages in which these may be found. For this reason also, if anyone hopes to learn at once how to rival Elkington in the art of electro-plating, or even, having got a Smee cell and half a pint of gilding solution, to at once proceed to gild his watch case or chain, he may as well resign himself to disappointment; he must go through an apprenticeship, by first learning thoroughly how to deposit copper in any required condition; this is a cheap and manageable process, and all the secrets of electro-metallurgy can be learnt there, and, once mastered, success in the other departments is assured, and only slight instructions are necessary for each special case.

311. The first thing essential to be considered is the source of the force, i. e. the best form of battery to employ. We require a battery easy of management, giving a large current at moderate cost and of tolerable constancy. Much will depend upon the amount of use to be made of the apparatus, for the conditions are very different when the instrument is to be kept steadily at work, and when it is to be used only by fits and starts. For most purposes the Smee is to be selected before any other ordinary form; but a careful study of the chapter treating of the different batteries will enable the reader to select the form most suitable to his purpose.

312. The basis of all knowledge is experiment, and the very essence of experiment is exactness; and this latter can be obtained only by regular measurements, a matter rarely attended to in electro-metallurgy. It is impossible to urge too strongly, alike upon the learner and the practical operator, the advantage of

keeping in the circuit a suitable galvanometer which will always show that operations are going on properly, call attention to any irregularity, and measure at every instant the actual work doing, while showing the effect of any variation in the conditions. In this way the work itself soon teaches its laws. For most purposes in metallurgy a vertical detector, § 181, will be found suitable, as not needing exact placing, and not being disturbed by neighbouring magnetic bodies, when, as is usual, two similar needles are mounted on the axis with poles reversed. For experimental purposes, however, the instruments, §§ 179, 180, are expressly adapted, and many of the experiments and figures to follow relate to their indications.

313. The various principles and processes classed under the name of electro-metallurgy may be classified and studied under several distinct heads, and sound knowledge can be obtained most readily by carefully distinguishing these heads. The mere process of removing the several metals from their solutions is a part of the general theory of electrolysis, of which it is a practical application, that theory therefore should be carefully studied in Chapter IX., so that in each given case we may secure the metal in such conditions of cohesion, colour, &c., as we desire.

314. There are two completely distinct objects sought in different cases.

(1) We require to form a fresh object in metal which is to have a separate existence of its own, and must, therefore, possess a certain substance and strength; this class of work is usually called *electrotype*, such as forming of copper plates, solid vessels, duplicates of coins, medals, &c., and divides itself into the two cases of deposits on metals, and on non-metallic models the formation of which has to be undertaken.

(2) We require the newly-formed metal to incorporate itself with that on which it is placed, and which it is our object to protect from atmospheric and other influences or to beautify; this class of work is called *electro-plating.*

This classification would appear to be the really important one, but this is not the case; for the result is simply a detail of the first head in the next classification to be considered.

(1) The preparing of the object to be deposited upon, including moulding, cleaning, &c.

(2) The actual deposition; selection, and making of the required solutions, and regulating the electrical energy for the due performance of the required work.

(3) The finishing off the completed work. The first and last of these are in the main mechanical operations, and may be considered together.

315. **The Preparation of the Objects.**—Here the first question is: Do we require an adherent deposit, a superficial plating; or do we wish a removable coating, an electrotype? The first can only be obtained upon a metallic surface, and that surface must be of a metal not acted upon to any great extent by the solution to be used; thus it is in vain that we may try to get a coating of copper on an object of zinc or iron in a solution of sulphate of copper. This comes under the second head, however.

To obtain an adherent deposit there is one essential—cleanliness. And in this sense that word means the perfection of that virtue, not such cleanness merely as will satisfy a scullery-maid, or even her mistress, as to the plates and dishes, but chemical cleanness, the absolute absence of any foreign matter whatever, as such matter, however clean to ordinary ideas, is *dirt*, as Lord Palmerston defined it, matter in the wrong place. Thus, a piece of silver or gold taken off a shelf, however bright and clean it might look, would not take an adherent coat if put into a coppering or silvering cell and deposited upon; on burnishing it probably, on heating it certainly, the coating would blister and strip. The reason is that every substance whatever has a film of air closely attached to it, and the deposited metal forms on this film and not in molecular contact with the metallic surface; thus, in the case considered, the air, however pure it may be, is dirt—i. e. it is in the wrong place, between two surfaces we want to be themselves in absolute molecular contact.

If a surface has been cleaned to perfection and it be touched with a dry finger, on that spot the deposit will be non-adherent, and in many cases, if cleaned by liquid processes, even a momentary exposure to air will cause the formation of a film of oxide, &c., which, infinitesimal and even undiscoverable as it may be, will still prevent adherence, so that it is of extreme importance to understand what is meant by chemically clean, and how to secure that condition, if it is desired to avoid the most mortifying disappointments.

If, on the other hand, we desire a non-adherent removable deposit, we require ordinary cleanliness, the removal of loose extraneous dirt, and everything which would interfere with the formation or beauty of the deposit, but we must carefully deface chemical cleanness of surface by means described, § 321.

316. Articles may be cleaned either by dry or wet processes, the first, of course, consists mainly of brushing with the aid of polishing materials, fine silver sand, emery, tripoli, whiting and rouge, according to the nature of the article. It should be observed here that whatever condition we desire in the finished article we must produce in the object before commencing deposition: bright parts

should be burnished, and all roughness of workmanship smoothed off, and all file marks and scratches carefully removed. There is, however, this limit to this observation, that in adherent coatings absolute finished polish is not desirable, and even though it is proper to burnish the required parts so as to give a close finish, yet before actual deposition this burnish should be slightly and superficially removed, as perfect adherence is less easy to obtain on an absolutely smooth surface, though an instant's dipping in strong acid is enough to give the burnished surface the capacity of adherence without deteriorating from the beauty of finish.

The best cleaning and polishing apparatus is in the form of circular brushes mounted upon a lathe; in factories this is always employed in the form of the scratch-brush lathe, a rough affair driven by steam or by a common treadle, with fittings to supply a constant drip of various liquids found to facilitate the action, such as soap and water, stale ale, &c. Amateurs who have no lathe employ the common hand brushes of bristles of various degrees of stiffness; for the harder work of cleaning, the wire "card" is very useful, and for the more delicate work scratch brushes are employed, in the form of bundles of very fine wire bound round with stronger wire (which is unrolled as the wires wear down). These are made usually of hard brass, but iron is also needed, and in some very delicate work, brushes of spun glass are useful. The same sort of brushes are employed in finishing off the articles after deposition. These matters being purely mechanical and self-obvious to anyone after a little practice, it is not necessary to go further into detail about them.

317. Many metallic substances it is advantageous to heat and plunge into acids; but this must not be done with objects which are soldered, or whose temper or hardness it is necessary to preserve. As a rule, the first thing to be done (where this heating is inapplicable) is to remove the greasy films which most objects acquire either in use or course of manufacture: this is effected by boiling and rubbing in a solution of caustic soda, made by boiling about 2 lb. of common soda crystals with milk of lime, produced by slaking ½ lb. of quicklime with hot water and well stirring; this will produce a gallon of suitable solution, from which it is not necessary to remove the carbonate of lime formed, as it will assist in the cleaning. The boiling must be effected in an iron pot, not tinned, as tin would be dissolved and deposited upon objects afterwards. After this alkaline bath the objects should be well washed in several waters or under a running stream. They are next cleaned in acids, and again very carefully washed before passing into the depositing vessel; but this stage requires a classified consideration based on the several metals of which they are composed.

(1) *Silver* may be washed in dilute nitric acid, then dipped in strong nitric acid for an instant and washed. It will require no further treatment. There must be no hydrochloric acid or chlorine salts present.

(2) *Copper, brass, and German silver* are immersed in a pickle composed of water, 100 parts; oil of vitriol, 100 parts; nitric acid, specific gravity 1·3, 50 parts; hydrochloric acid, 2 parts.

The nitric acid is of the strength sold as double aquafortis. An acid prepared for the purpose is sold as "dipping acid." Two vessels should be employed for this acid; one fresh, for a final dip of an instant or two, and one partly spent, in which the principal cleaning is effected. If there are green spots of verdigris on the object, these should be first removed by rubbing with hydrochloric acid.

For coppering, this cleaning would be enough; but for silvering and gilding, it is better to coat the surface with a thin film of mercury. This is effected by means of a solution of 1 oz. of mercury in nitric acid with 3 parts of water diluted to one gallon; there will form a grey or blackish deposit over the surface, which, on brushing softly, gives place to a brilliant coating of mercury; the object should be transferred to the depositing cell the instant this is obtained, otherwise it soon tarnishes, and will require fresh preparation. There should be a little free nitric acid in this mercury solution, and whenever there forms a black deposit somewhat adhering, it is evidence that the mercury is becoming exhausted. Solder, lead edges, &c., give much trouble, as it is very hard to prevent a black line forming at the junction which prevents silver taking; these spots require treatment with a stronger solution of mercury, or a plan I have somewhat modified from Watt's may be often used: to a soft brush (camel's-hair pencil), tie one or two iron wires of No. 25, or thereabouts, so bent that the points closely follow that of the brush, which is to be dipped in a weak solution of sulphate of copper free from acid, and drawn over the solder, the iron touching it; a reaction is set up, which causes the copper to be deposited in a thin adherent film, on which the electric deposit will fix itself. Nitrate of copper, prepared by dissolving the metal in weak nitric acid, is even better than the sulphate for this purpose.

(3) *Britannia metal, pewter, tin, and lead* should not be dipped in the pickle, but rinsed in a fresh caustic soda or potash solution, and transferred at once (without passing into water) into the solution for silvering. The reason is that the oxides of tin and lead are soluble in caustic alkalies.

(4) *Iron and steel* are soaked in a solution of 1 lb. of oil of vitriol in a gallon of water, with a little hydrochloric and nitric

acids added. Cast iron requires somewhat stronger solutions and very careful rubbing with sand, &c. Steel, on the other hand, requires weaker solutions. They may often be effectually and speedily cleaned by connecting them as anodes to a single cell in this solution, using a plate of copper as a cathode.

(5) *Zinc* may be treated similarly, but it is desirable to finish with a dip into stronger acids before the final washing. Most of the French "bronzes" are made of zinc, and some do well for silvering on. In these last cases no copper or other metals should be dipped in the baths, and soldered joints must be treated as described above.

These latter classes require special preparations and treatment in the depositing baths, but just the same classification is advantageous there as in the cleaning processes, and the details will be given when treating of the depositing processes themselves.

318. PREPARING OLD WORK.—In replating old goods it is essential that the former silver, &c., should be removed, otherwise a black line forms at the junctions, and sound deposit cannot be obtained. In factories, this is usually effected mechanically by the scratch brush, with the aid of oil and rotten-stone, and the débris are collected and reduced to recover the metals. The metals may also be removed chemically.

(1) *To Remove Gold.*—Immerse in strong nitric acid, and add crystals of common salt; after a time, when the acid is exhausted, evaporate to dryness, and fuse with soda or potash to obtain the gold.

(2) *To Remove Silver.*—Immerse in pure oil of vitriol, and add nitrate of potash (saltpetre), and heat. This may be done in a copper vessel. When spent, dilute largely, and throw down the silver with scraps of zinc, or as chloride, by adding hydrochloric acid. The silver may be recovered from this by fusing with carbonate of soda, or by mixing with zinc cuttings and sulphuric acid, or it may be used for a chloride of silver battery.

(3) *To Remove Copper.*—From silver, boil with dilute hydrochloric acid.

(4) *To Remove Tin and Lead.*—A hot solution of perchloride of iron (jewellers' rouge, or the druggists' carbonate of iron dissolved in hydrochloric acid) will dissolve copper, tin, or lead without attacking silver or gold.

319. VESSELS.—For all the foregoing processes, no better vessels can be had than the best hard brown earthenware; for small articles, a kind of basket is made of this material with handle for dipping and shaking about. The same material is available for the plating liquids themselves, though glass is preferable for small operations. For washing, it is well to arrange a succession of

vessels with spouts, or slightly inclined, at such a level below each other that a stream of water will flow from the highest to the lowest, so that by rapidly passing the object from the lowest upwards, it is perfectly cleaned; for amateurs, the simplest plan is to hold them under a water tap, and remove them in a pan of water straight to the next stage.

320. CONNECTIONS.—All objects must be securely connected electrically with copper wires. Where it is possible, these should be soldered, but usually the connection has to be one of mere contact; for large objects, several wires should be provided; for small ones, such as spoons or forks, little stirrups of No. 30 or 32 wire are best, fixed to a stouter wire, and the points of contact with the object should be frequently shifted, otherwise it will be defaced by a mark when finished. For this reason, the wire actually in contact with the object should always be as small as possible, though it may be fixed to a stouter wire at a short distance. These connections may generally be attached before cleaning: if otherwise, they should be fixed under water, and with the hands scrupulously clean.

The mode of connecting non-metallic objects is described, § 331.

321. REMOVABLE DEPOSITS.—ELECTROTYPES.—The objects on which these are to be formed should be made simply clean by the removal of loose dirt; they should then be lightly rubbed over with a tuft of cotton wool moistened with turpentine, with a piece of beeswax the size of a pea dissolved to the quarter pint; this, when dry, will not interfere with the deposit, but will prevent adhesion. The back and all parts not intended to be deposited on should be covered with varnish or wax for acid solutions, or with a solution of guttapercha or indiarubber for cyanide solutions, which dissolve fatty and resinous substances. Paraffin is even better for these in cold solutions, but is of course useless when heated, as in gilding. See also § 331.

322. MOULDS.—Many of the objects desired to be reproduced have to be deposited, not on the objects themselves, but upon copies or moulds made from them, and some judgment is necessary in selecting the best materials for the purpose; we have to consider (1) of what material the original object is made, and (2) the material which will work best with this, and at the same time suit the particular process of deposition to be used; thus we must avoid using a material which might injure the original, and also one which would be acted on by the solutions; this latter being the case with all resins, wax, and stearine in cyanide solutions. We should regard first the objects to be moulded from, the processes being considered in the order of their advantage.

(1) *Metallic objects, coins, and medals*, &c., are moulded from in

fusible metal, guttapercha and marine glue, plaster of Paris, or composition; the surface should generally be rubbed with sweet oil to prevent adhesion; or if it is not objectionable, they may be well polished with plumbago.

(2) *Plaster casts* may be moulded from in plaster, in which case they must be rendered perfectly non-absorbent by the means described; they may also be copied in composition, in which case they must not be so prepared, or the object and mould will adhere, but must be so saturated with water that the surface is moist but not wet, at which stage the composition can be poured on.

(3) *Wax or Sulphur* objects may have moulds taken from them in plaster.

323. **Fusible Metal or Clichee.**—This material has the advantage of requiring no preparation to render it conducting, and is connected by simply pressing a heated tinned wire on any suitable spot, and protecting by varnish the parts not to be deposited on. The principal objection to its use is the dearness of bismuth, to which the ready fusibility is due. The mixtures most available are:

	Lead.	Tin.	Antimony.	Bismuth.	Fuse at
(1)	5	3	0	8	212°
(2)	5	4	1	8	..
(3)	1	1	0	2	200°

The metals are to be melted and added in the order in which they are arranged, stirred well together, and granulated by pouring gently into water. The alloy should then be melted afresh, and granulated two or three times to insure complete mixture. The value of these bismuth alloys arises from their assuming (as solder does also) a pasty condition before setting, and from their expanding in the act of cooling, thus taking a very sharp impression. A small paper case, such as a pillbox cover, a little larger than the medal to be copied, is slightly oiled, and sufficient melted alloy is poured in; it is then placed on a table, and stirred with a piece of card till it becomes pasty; its surface is then lightly swept free of any oxide by passing the edge of a card over it, and the medal, which should be attached to a holder, is brought sharply and firmly down upon the metal, pressed till it sets, and left on till the whole is cool.

324. **Guttapercha** is a good moulding material, and takes black-lead very readily; but as it shrinks in cooling, it must not be used to surround any object, as it would not be removable without injury; for the same reason it requires to be kept under strong pressure until cold; it is, therefore, best adapted to flat objects. It should be well softened in boiling water, and worked together in

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cool water, and again heated to boiling temperature and formed into a ball, which, being applied to the middle of the surface, is worked out in all directions at the edges of contact, so as to prevent any air being enclosed, and as soon as the whole is evenly covered, it should be put under a weight or press to cool, for which purpose an ordinary copying press answers perfectly. For large surfaces sheets may be used. They should be warmed, one edge brought carefully in contact, and the sheet gradually lowered while an assistant presses it up to the object; in this case the sheet must be new, as guttapercha oxidizes and forms a hard surface, which would break up and deface the mould. A mixture of two parts of guttapercha melted, and one part marine glue added, is in some respects superior to guttapercha alone. The glue, which has many uses, is best bought, as it is troublesome to make; it consists of 1 lb. caoutchouc, soaked for twelve days (till dissolved) in four gallons of coal naphtha; to each pound of this liquid two pounds of shellac are added, and heated in a closed vessel till incorporated. For guttapercha moulds the objects should be lightly oiled to prevent adhesion.

325. **Plaster of Paris.**—This is sulphate of lime, or gypsum, deprived of its water of crystallization. This is effected by heating to 500° Fahr.; if heated beyond this, it loses its power of setting, but when properly prepared it has so strong an affinity for water that in combining with it a solid substance is formed. The plaster should be fresh, and it is best to warm it before use in an oven, or over a fire, till it bubbles slightly; it should then be dropped lightly into a vessel of water, the excess of water poured off, and the material worked up to a paste capable of being poured out. The object to be copied is oiled, and if flat is placed in a frame of sufficient depth and covered with a thin paste of plaster, brushed in to secure freedom from bubbles, and then the plaster is poured over till sufficiently thick. It should be allowed to set thoroughly before removal, and then baked gently to remove moisture. It must be thoroughly saturated with a resisting medium—tallow, stearine, or paraffin; and the best mode of doing this is to place the mould with its face upwards in a vessel containing a little of the melted substance, and heat till the face shows that the protecting agent has been drawn to it by capillary action; then warm the mould gently by itself to remove any excess, and allow it to cool before applying the plumbago. Some use boiled oil, but it is not safe, as it requires to be very thoroughly dried before it can be trusted in the solution. Moulds well made can be repeatedly used, and the saturating material can be recovered afterwards by breaking into pieces and boiling in water, when the substance will melt and form a film on the water when cold.

326. **Wax Composition.**—Many materials have been recommended; the object of the mixtures is to prevent undue shrinking: this is partly effected by addition of powders, such as flake white, carbonate of lead (which, however, is partly acted on by the solutions), plaster of Paris, and plumbago or powdered graphite, which assists in producing a quick and even coating. The best mixtures are

Wax.	Resin.	Stearine.
3	..	1
1	1	..

The wax is the ordinary yellow beeswax, and the stearine such as is used for composition candles; good hard mutton suet may be substituted. The materials should be melted together gently two or three times, and when used should be poured on the model just as part of the material begins to set, not while hot. The object is to be oiled and placed in a flat vessel, or if round, as a coin, a piece of paper should be tied round it; it should be slightly inclined when the material is poured on, so that this may rise steadily over the surface, and drive off all air bubbles; when set, the paper band should be removed and the whole allowed to cool for several hours before the mould is detached.

327. **Solid Objects.**—Moulds of these have to be taken in two separate parts. They should be bedded to half their depth in fine sand or other powder, in a case large enough for the purpose, and three or four pegs or wires fixed in and projecting from the surface of the sand; the moulding material is then poured on, and when cold, the case is reversed, all the sand removed, the surface of the mould trimmed and prepared so as to prevent adhesion, and then material is poured on so as to enclose the object entirely; when cold the two halves are separated; deposits may be made upon each mould, and the edges united with solder. Some objects may require more than two divisions of the mould, but by similar means (which are, in fact, the ordinary process for casting metals) any complicated object may be copied, unless the elastic mould process is preferred.

328. **Busts and Undercut Objects.**—The latter cannot be moulded from direct. They can have a mould taken in the elastic material next described; in this may be formed, of wax composition, a duplicate of the object, from which again a mould may be made of plaster and the wax melted out, thus producing a hollow mould which will be necessarily impervious, and *in which* the deposit can be effected. Hollow silver vessels have been made in this way, by depositing a copper coating on the wax duplicate, which being melted out, silver is deposited within the copper, which is then dissolved off by the process given.

329. **Elastic Moulds.**—Glue is soaked in water till soft, and then melted in a water-bath as usual, and to it is added one fourth of its dry weight of treacle; this forms an elastic composition such as printers' rollers are made of, and if carefully treated may be melted and used many times. To make the mould, a vessel is to be taken large enough to contain the model, which must be itself duly prepared to prevent adhesion, and if hollow, filled with sand and a stout paper pasted over the opening; the vessel is to be oiled inside, the object stood within, and the composition poured gently over it. After standing 24 hours to cool and set, the whole is shaken out of the vessel, and a sharp clean knife run through from top to bottom in the most suitable line, when with care the mould may be opened and the model withdrawn; the mould is then closed and a stout paper cylinder formed around to support it. This mould is, of course, unfit to use with liquids; a fresh model is formed within it of some mixtures of wax, &c., the composition of which is intended to produce a material which will take a good cast, and will also melt at a heat which will not injure the mould, for which reason also it should be poured in just when it shows a commencement of setting, not when just melted. Equal parts of beeswax and resin, with a little tallow and powdered graphite, may be used, but the preparation patented by Mr. Parkes is best for forming deposits direct upon the model; it consists of 5 lb. beeswax, and 5 lb. deer's fat melted gently together, and 6 oz. or 8 oz. of the following solution added:

Phosphorus Solution.—1 part by weight of phosphorus dissolved in 15 of bisulphide of carbon: this has the property of reducing the nitrate of silver and chloride of gold, weak solutions of which are to be provided and employed as described, § 330.

330. **Insects, Flowers, Lace,** and many other delicate objects can be given a beautiful metallic coating.

(1) Immerse in a solution composed of the phosphorus solution (§ 329), to which is added (in proportion to 1 lb. of phosphorus), 1 lb. wax, 1 pint spirits of turpentine, and 2 oz. of caoutchouc dissolved with 1 lb. of asphaltum in bisulphide of carbon.

(2) Immerse in solution of nitrate of silver containing about 1 dwt. of silver to the pint. The object blackens, when it is to be removed and washed; it will then take a deposit, but will be improved by the next solution.

(3) Immerse in solution of chloride of gold containing 4 grains of gold to the pint.

The object should be first carefully attached to the connecting wire before the immersions, and after them washed by gentle dipping into several waters, not with any great agitation, as the metallic coating is a mere non-adherent dust. By this process there may be made the most beautiful objects to be conceived, by a careful selection of the feathered grasses, and some of the finer-leaved flowers; coating with silver, copper, and gold, and producing different colours on these metals, which should of course be in very thin films; they need, however, to be put under a glass shade cemented to its stand so as to be air-tight. Elegant ornaments may be made also from some of the finer Parian and other earthenware covered in this manner, and variegated with bright and dull parts and colours. *Leaves*, &c., may also be copied by taking a flat sheet of warmed guttapercha, dusting over with gold bronze, or fine plumbago, laying on the leaves, sea-weed, &c., then covering with a polished metal plate, and screwing gently up in a press.

331. **Conducting Surface.**—The best known process of rendering the surface of non-metallic objects conducting, is to coat them with a film of plumbago or blacklead. The ordinary article sold for household use cannot be relied on; it is best obtained of a dealer in scientific apparatus, because, though they charge a very long price as compared with the common article, a little also goes a very long way, and much trouble is saved. The gas carbon used for plates, &c., if very carefully ground in water, answers perfectly. The connecting wire should be carefully adjusted to the mould, by imbedding in the plaster, or in other materials, by warming and pressing in, and great care must be taken to make the plumbago film commence in contact with this wire. In large moulds it is desirable to arrange the conductor before moulding, and to solder to it (within the space to be occupied by the mould) a number of fine copper wires, the ends of which are to be placed in contact with various parts of the surface of the object, selecting points not likely to be defaced, and especially the deepest points of any cavities; the points of these wires will form so many starting points and junctions with the plumbago; with medals, &c., it is best to take a wire all round the circumference. Wires may be applied during the first period of depositing, so as to touch the finished mould on its face and form temporary connections which are to be taken away as soon as a complete film has formed over the whole surface. The plumbago is best applied with a camel's-hair brush, working it lightly in, and occasionally breathing lightly on the surface if the powder does not readily adhere; in some cases, where there is obstinate non-adhesion, the spot may be held for an instant over the mouth of a bottle containing spirits of wine. In some cases plumbago is unsuitable, as when a hollow vessel much undercut or chased is to be copied; in this case the phosphorus solution and process described § 329 is best employed. I have advised the use of powdered graphite in moulding materials, with the object of facilitating this coating and connection, as it renders the materials

partially conducting. In this case (and wherever plumbago has touched accidentally parts not intended to be deposited on, and also in medals when only the face is intended to be copied and yet there is a wire all round) every part not to be deposited on should be coated with a non-conducting film; either resin or copal varnish or melted wax will answer in acid solutions, but paraffin or solutions of guttapercha or indiarubber should be used in cyanide and other alkaline solutions. Napier gives a protecting varnish for the latter, which, however, I have not tried. "Pitch is easily affected alone, but on boiling it in potash a heavy and dirty sediment is left, destitute of any adhesive property; on putting a quantity of this sediment into a pot nearly filled with melted pitch, a violent effervescence will take place, setting free a volume of white fumes having a creosotic smell. After all effervescence has ceased, which will not be for a considerable time, and when all the mass seems to have been acted upon, the process of making an excellent protecting coating is completed—a coating which will not yield in the solution, and which is at once both good and cheap, its only fault being its brittleness." This applies rather to metal surfaces to be protected than to parts of non-metallic moulds.

332. The general laws of the electric circuit studied in Chapter VII. govern the deposit of metals. In the older works on the subject two terms, Quantity and Intensity, § 240, were much dwelt on, and the ideas thus set forth still retain their ground and cause much confusion. It was upon these ideas that the leading and most original writer upon the subject, Smee, based his laws, and in order to derive from these past labours what good they can now furnish, and then show how much more advantageous are the results of later knowledge, I will now give an abstract of Smee's own experiments and the laws he deduced from them.

When a metallic solution is subjected to voltaic action the metal is reduced, but not always in the same state. If we dip a knife into a solution of copper sulphate, bright copper is deposited; but if we immerse a piece of zinc, the copper is thrown down in a black powdery mass. Again, if zinc is immersed in an ammoniacal solution of copper sulphate, the metal deposited is bright, while iron in a dilute and acid solution of the sulphate reduces black metal. Though these are apparently simple chemical actions, the same diversity of deposit is obtained electrically. Thus, if we take a saturated solution of copper sulphate, and pass through it a feeble current, crystalline copper is deposited; if we dilute the solution with two, three, or four times its bulk of water, the metal is deposited in a flexible condition (which Smee calls "reguline"); on dilution to a very great extent, the metal deposits as a fine black powder. By placing in a tall vessel, quietly, so that they do not mix, a strong solution, then a weaker, and lastly water with traces of acid, after a little while a perfect gradation of strength is reached, and if two copper plates, extending through all the strata, are connected to one galvanic cell, the varying conditions will produce all these classes of deposit at the same time on a single electrode—black powder at top, reguline metal at the middle, crystalline copper at the bottom. From this fact the conclusion is to be drawn that the nature of the deposit depends upon the strength of the solution. Again, taking a solution of copper, with some acid in it to make it a good conductor, and using with it first a very small cell, then two or three ordinary cells arranged in series, and then a very intense battery, we, with this one solution, again obtain, first a crystalline, then a reguline, and finally a black deposit; showing that the amount of electricity passing also controls the state of the deposit. Therefore " we are forced irresistibly to the conclusion that to obtain with certainty any particular metallic deposit, we must regulate the galvanic power actually passing to the strength of the metallic solution. This is the fundamental principle—the very essence, in fact, of " electro-metallurgy." Hence are derived these laws:

I. Black deposit is produced when the current is so strong, as compared with the strength of the solution, that hydrogen is set free at the negative plate.

II. Crystalline metal is deposited when the current is so weak, as compared with the solution, that there is no tendency to evolve hydrogen.

III. Metals are reduced in the reguline state when the current so balances the strength of the solution that it is insufficient to actually set gas free, but produces a strong tendency thereto. There are also two forms of crystalline deposit—one of a sandy, loose character, due to deficiency of the quantity of current in a strong solution; the second from a large quantity of current as compared with the size of the plate; thus, by using a large anode with a small cathode in a strong solution, large crystals of extreme hardness are produced.

333. There can be no doubt that Smee, by setting forth these ideas, did much towards developing electro-metallurgy; yet they are only very partially true. The experimental bases are imperfectly comprehended, and the laws deduced are incapable of exact application.

Anyone who has mastered the relation of current to force and resistance will see, when it is pointed out, that the fundamental experiment is fallacious; for though the same battery and electrodes are in action, the rate of current will vary at different heights, and no certain deduction can be made, except this one, of supreme practical importance—that stratification of the liquids should be carefully avoided by frequent stirring up. An instructive experiment may be arranged, which does really show the relation of deposit to strength of solution, by preparing six cells, containing—

1. Saturated solution of copper sulphate.
2. " " " 1 part, water 2 parts.
3. " " " 1 " 4 "
4. " " " 1 " 8 "
5. " " " 3 parts, water containing $\frac{1}{10}$th in bulk of sulphuric acid 1 part.
6. 1 part of No. 5. Water, 1 part.

These being arranged in series by means of plates of copper 1 × 1 inch, coated on one side with paraffin, have the current passing under perfect control and necessarily equal in all. By using plates of this size the relations of current to area of surface are also studied.

In such an experiment I have found differences in the qualities of the copper, but nothing like what occurs in Smee's experiments. The teachings as to strength of solution and its influence were but small, for I found good deposits in all with great ranges of currents. The teaching as to *quality* of solution was, however, very important, for in all cases the deposit in No. 5 was by far the best—bright coloured, silky surface—even in thickness, and tough in texture; No. 6 came next, and No. 1 was the worst.

334. The real laws of electro-metallurgy are the ordinary laws of the current known as Ohm's formulæ; these have been already fully examined, and we need now deal only with their special application. We have to balance the electromotive force and the resistance of the battery against the resistance of the depositing cells in proportion to the rate of deposit we require, according to the formula $\frac{E}{R} = C$, and we must regulate the *density of the current* §§ 337, 340 (which we have hitherto had nothing to do with) to the size of surface we have to deposit upon, and the quality of metal we wish to produce.

335. **Electromotive Force** should be kept as low as is consistent with proper speed of working, because it is expensive; that is, we should use no more cells than are necessary in series. Each reaction has an electromotive force suited to it; less will either not work or work very slowly; more is waste, because

instead of adding cells to force the work, we ought to correct the resistances to the natural conditions of the work. We should only add cells when we wish to produce a more rapid deposit than the natural state of resistances allows, and then the quality of the deposit is likely to suffer.

The electromotive forces of the batteries useful for electro-metallurgy are, roughly and for average continuous working, in volts:

1. Copper, zinc, in acid	·3
2. Platinized silver	·5
3. Daniell	1·
4. Nitric acid cells	1·6

These give results in BA units of current or vebers; and these, multiplied by 5·68, give the current in chemics, and therefore express at once the weights of any metal deposited in a given time by aid of the equivalents given in Table XIII., p. 212.

The electromotive forces required for depositing metals are in volts about:

1. Copper	·5 to 1
2. Silver	1·5 „ 2
3. Gilding	·3 „ ·5

That is to say, 1 Smee or Daniell is enough for coppering, 3 Smees or 1 Grove for silvering, and 1 Smee or copper cell for gilding; providing in all cases power is not wasted by needless resistance, bad connections, thin wires, &c.; but higher forces are required to obtain quick deposits.

336. **Resistances** should be balanced so as to be about equal in battery and cell. This may be roughly put thus: the surfaces exposed of zinc and negative in battery, of object and dissolving-plate or anode in depositing cell, should all have nearly the same area (except in gilding, where resistance is needed). The resistance may be greatly varied in the depositing cell by changes in size of anode and distance apart. Thus it will be seen in §§ 341–3, that in some cases it is very desirable to have some distance between the plate and object, which increases resistance. In these cases this may often be met by enlarging the size of the anode, which diminishes resistance.

It is desirable, however, to use large plates in the battery, because large cells work best; and then if small objects only are to be deposited on upon occasion, if the density of the current is too large, owing to the disproportion, external resistance (as a length of wire) may be introduced, enough to reduce the current to the proper proportion; or if the construction of the battery permits, the distance between the plates or that in the cell may be increased sufficiently for the purpose; or a smaller anode may be used, though this is often disadvantageous.

337. **DENSITY OF CURRENT.**—According to Ohm's formula $\frac{E}{R} = C$ we can calculate, knowing the elements, the current produced in any case. Thus taking 1 Daniell cell as 1 volt force, and assuming the total resistance as 1 ohm in a circuit in which copper is being deposited, we have 1 veber per second, or a current equal to 5·68 chemics or grain equivalents per ten hours; under those conditions the galvanometers (described, §§ 179, 180) would mark 5·68; and this, multiplied by 31·75, the equivalent of copper, shows that copper is being deposited at the rate of 170 grains per ten hours, or 17 per hour. This is the *total* current, and it is evident that the conditions of the deposit, the quality of metal, &c., will depend wholly on the extent of surface over which it is spread; on a large plate it might be a mere film, on a wire it would be a thick coat. This is what is meant by *density of current.* Now there is a relation between density of current and the state of saturation of the depositing solution, and they increase together; the more dense our current, the more rapid our deposit (not from the solution or total deposit, but for a given area), the stronger our solution may be, and must be to get good metal. But very strong solutions have drawbacks, to be afterwards considered; and we cannot conveniently alter the strength of our solutions continually. We must ascertain, then, what range of density of current suits our solutions, and then be careful to keep the conditions within that range. If the density of current be too great, we get a sandy or even black powder as a deposit; if it is too slight, we get a crystalline brittle deposit. Happily, the range is considerable within which good results may be obtained.

As yet this subject has never been philosophically treated; the facts are known and the matter is loosely described in works on the subject; but no one has, within my knowledge, attempted to deal with it definitely. There is in fact no recognized unit of density of current, because few people in practice have definite ideas upon the current itself. In order that my readers may remedy this, I will fix upon a unit in accordance with the system used throughout this work. Our unit of current is the chemic; call our unit of surface one square inch, then the unit of density of current becomes one chemic per square inch.

338. The object of having a galvanometer in circuit will now be seen, as well as the special advantage of the forms, §§ 179, 180. Any galvanometer will show if all is going on right, but these show at

a glance, not only the total work doing, but in electro-metallurgy will tell us the quality of metal depositing, and enable us to regulate the conditions to produce the effect we desire.

339. **Tension.**—The ideas attached to this word now replace those formerly described as due to "Intensity." We are concerned with them at present chiefly as part of the conditions for maintaining the requisite current. But they have also another bearing to which little attention has yet been paid. As seen, §§ 289, 295, the plates or electrodes act as condenser-plates, and the molecules in contact with them will necessarily be under different conditions according to the tensions, which depend upon the electromotive force of the circuit, the resistance between the plates, and the proportion this bears to the total resistance of the circuit. The resulting effect of high tension at the electrodes (that is to say, of a great distance or resistance between them overcome by using high electromotive force) is a deposit of hard metal; low tension produces a softer metal, and this difference is due to the molecular conditions existing at the electrodes themselves; for all other conditions, such as *strength* of current or rate of deposit, and *density* of current, or size of the electrodes, may remain the same, while the varying hardness of deposit is controlled by the difference of tensions.

340. **Arrangement of Objects.**—This includes the consideration of several distinct sets of principles, as to each of which it is very desirable to obtain clear conceptions: 1. The position—horizontal or vertical. 2. The relative proportions of object and anode. 3. The distance to be maintained. As to each of these, I will give experimental illustrations, which I recommend the student to follow out, and even those practically well acquainted with the subject will find their knowledge become much more definite and exact by carefully examining the conditions of such systematic experiments. To obtain their full teachings it is essential to have in the circuit a galvanometer whose readings are definite.

The solution to be used is that already shown to be best for all objects not acted upon by the acid—viz., 3 parts saturated solution of sulphate of copper and 1 part of dilute sulphuric acid, 1 to 10 of water by measure. I have tested the range of density of current such a solution will allow, and will here give the experiments and results, each having been continued for such time as to give the same weight of copper per square inch of surface.

The unit of density is that taken § 337—viz., 1 chemic of current or 1 equivalent in ten hours (that is, nearly 32 grains of copper), upon 1 square inch of surface; and in the experiments a quarter equivalent was deposited, i. e. 8 grains, giving a thickness equal to stout paper. The experiments were all made with a large Daniell's cell, and the current varied by means of resistances.

1.	·1	unit	taking	30	hours:	excellent coating.
2.	·2	„	„	15	„	good tough copper.
3.	·5	„	„	5	„	a beautiful deposit.
4.	1·	„	„	2½	„	very good.
5.	2·	„	„	1¼	„	sandy at edges.
6.	3·	„	„	¾	„	bad all round the edge.

The first four deposits were hardly distinguishable; the metal was tough and tore without cracking. As with all deposited, and therefore crystalline, metals, none would bear doubling flat; but after heating red-hot, they could be hammered double, and opened without cracking. In 5 and 6 the middles were good enough, but the metal round the edges was of a loose, sandy nature.

It would therefore appear that the *rate of deposit* of copper should not exceed 1½ units, but that it may be as much less as is desirable without injury to the quality of the metal.

Large, and especially flat, surfaces will allow a quicker deposit than small objects; objects having sharp edges or projecting points require slower deposit and special precautions, §§ 341, 343.

341. POSITION.—Place a strip of copper, at least 4 inches long, vertically in a vessel with a corresponding anode, and pass a small current, leaving the apparatus undisturbed for some days. It will be found that the anode is dissolved away mostly at the top, and if thin, it will be perforated with holes, or even cut completely through at the surface of the liquid. The cathode, or receiving plate, on the contrary, will have a thick coating at the bottom and least of all at the top. The edges will be formed of groups of nodules, forming a thick edging, and the lower corners will show this particularly, and bulge out somewhat. Besides this, in all probability, the whole surface will be marked by vertical lines, mostly commencing in a dot, and forming a sort of prolonged note of exclamation (!). Now repeat this experiment in a rather long, narrow trough, or in a vessel with a porous division, or even in two glasses connected together by a siphon or some thick cotton wick, and use a saturated solution of copper sulphate with no acid. In a short time the anode will become coated with small crystals of sulphate of copper, which will entirely stop the current, and the previously noted conditions will be exaggerated at the receiving plate or cathode. The explanation is to be found in the actions described, § 306, p. 263; at the anode copper is being dissolved and the solution becomes stronger; the newly-formed salt, being heavy, sinks, and leaves acid when present above; or if the solution is saturated it cannot be dissolved, and is therefore crystallized where formed.

At the cathode copper is removed from the solution, which, becoming lighter, rises along the face. Now take a thin glass beaker, containing water and some light powder, and hold one side close to a Bunsen's burner, and notice the conditions of a heating liquid; a constant stream will soon be generated, rising along the warmest side, flowing along the surface, descending along the cool side, and flowing along the bottom. This circulating stream is due to the different specific gravity of warm and cold water. Exactly the same conditions are produced by the same cause in the depositing vessel; we have a stream of lighter acid liquid rising up the cathode, flowing along the surface, and impinging on the anode, which is there chiefly acted on; this increases the weight of the liquid, and forms a corresponding stream down the anode and along the bottom, which, reaching first the lower part of the cathode, there delivers up most of its metal; in consequence of these two states, the line of least electrical resistance becomes a diagonal one, from the top of anode to bottom of cathode, instead of being uniform through the liquid and at right angles to the surface. Most writers describe this action as due to simple stratification of the liquid owing to differences of density. This is erroneous, as the liquid would not stratify; it is the circulating current of liquid which is the cause of the mischief, and the evil becomes greater as the height of the objects is greater. This current is the cause of the lines and spots. The slightest irregularity of surface (and all surfaces are, scientifically speaking, rough) deviates this current, and the obstruction grows every instant as the metal is deposited.

Now, take two good-sized plates and arrange them in the solution horizontally, one at the bottom, the other at the top; connect this latter to the zinc of the battery for the cathode. In a little while the current will be stopped if from one cell; if from several, so as to force its way, the cathode will be found covered with a loose friable deposit, or even a black powder, while the anode will be coated with crystals. Clean the plates and replace them, but make the lower one the cathode. Now a good, even deposit will go on; in this position all requirements are satisfied, the acid dissolves the anode, the product descends and gives up its metal to the cathode, while the liquid being uniform all over the surface, the electric current is evenly distributed. This is the best position, therefore, especially for large flat surfaces and deeply-cut medallions, &c., but it is rarely employed because of its inconvenience, which, however, is much exaggerated. The impurities of the liquid and of the anode are precipitated on the deposited plate and deface it; but this may be avoided by filtering the liquid before depositing, and placing above the objects a frame fitting the vessel loosely, and covered with muslin or net, upon the surface of which is laid a sheet of filtering or blotting-paper. Of course the leading wires must be coated with a protecting cement.

The usual position (and for nearly all except flat objects, the necessary position) is one of vertical suspension; in this case the point of suspension should be frequently changed, the liquids be frequently stirred up, and best of all, the objects kept in constant motion, if possible. Means have been devised to cause a circulation of the liquid, but they have mostly failed, for the very good reason that regular circulation of the liquid is, as already shown, the very thing to be most carefully avoided, unless it is directed in a course opposed to that which would be set up naturally. If irregularities are seen to be forming, they should be removed by filing off, &c., as they constantly increase; but care must be taken to attend to instructions as to the removal of objects, § 348, or else the deposit will be apt to form in non-adherent layers.

342. Relative Proportions of Anode and Cathode.—They should be nearly equal in extent; or, the anode should be slightly the larger; if other conditions as to position, distance, &c., be attended to, the relative sizes is a matter of little moment as regards the actual deposit going on, but if they differ much, the composition of the solution will alter, especially if large currents are passing. Fig. 63, p. 193, will assist in the understanding of these relations, and also teach how best to arrange the objects so as to equalize as much as possible the lines of resistance, and therefore of proportional current, passing from each point of the one surface to points on the other. As a consequence of the modes of transmission and action of the current described, § 306, there is not in all cases an equal solution of anode and deposit on cathode, and thus the liquid may be impoverished or enriched in metal according as the anode is too small or too large. This applies more to cyanide solutions than to acid ones, because the former are much more complicated in their chemical constitution, and are therefore much more liable to be modified under the influence of the current. But it will occur even in copper salts.

343. The Distance to be maintained.—Place two small plates of copper connected to a single cell in a large vessel of copper solution, at first about one inch apart, and note the deflection of the galvanometer; now gradually increase the distances and observe the steady fall of the deflection. This indicates that the resistance to the passage of the current increases with the distance between the plates. Bend the receiving plate into a V form, and present the edge towards the anode, and it will be found that the deposit will be thickest there, gradually thinning away. In the same way, if the receiving plate be a circle or square, and the anode be much smaller and placed near and opposite the centre, the deposit will

be found thick in the middle, and thinning gradually away upon the flat surface. The farther the anode is away, the less variation will there be in the thickness of the deposit. If now we draw plans of these arrangements and strike lines across, we shall see the reason is to be found in the principles of liquid conduction, § 233; wherever these connecting lines from anode to cathode are shortest, there will the deposit be the greatest; the electric current distributes itself through every possible path open to it in proportions exactly the opposite to those of the resistances each path offers. To get even deposits therefore upon the cathode, the anode should be equally distant from all parts of it. This is easy in flat plates, and these may therefore be arranged very close together; in circular objects the same result is obtained by surrounding them either with a large cylindrical anode or by suspending strips all round them. Whenever objects are irregular in form, and especially when the surface is deeply chased or undercut, it may be taken as a sound principle that the distance apart should be considerable in order to diminish the difference of the distances of the prominent and deep parts from the anode; in such cases it is desirable also that the action should be slow, in order to allow the exhausted liquor to be replaced in the hollows. This is of especial importance in coating non-metallic moulds; in fact, it is well in these to secure deposit first in the hollows, by presenting into them the point of a coated wire, as the only anode at first, for it is by no means uncommon, though very vexatious, to find these hollows obstinately refusing to take a coating at all when a large prominent surface around them has secured a coating, this being so much better a conductor than the film of plumbago. As a rule, better and more even deposits are obtained when the distance is considerable than when it is small; the drawback is that either the rate of deposit is diminished, or else, in order to maintain it, great battery power is required. These are elements of time and cost against distance, but quality of deposit is in its favour.

Another advantage of placing the anode and cathode at a considerable distance is, that it necessitates large vessels and a good body of liquid, conditions opposed to the setting up of currents, and tending, by the greater area of diffusion, to the maintaining a more uniform condition in all parts of the vessel. This remark applies, of course, to amateurs; in factories the vessels are always large, and the anode plates and objects to be deposited upon are distributed about, according to the number and form of the objects to be operated upon.

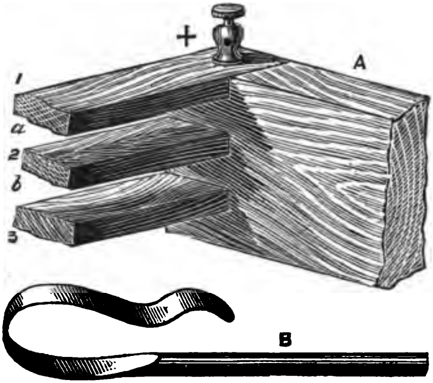
344. In some cases it may be desirable to control and vary the rate of action upon different objects immersed in the same solution, or to ascertain the exact amount of metal deposited upon such

objects. This may be easily effected, because a number of electric currents may be passed through the same solution without interfering with each other; it may even be effected from a single anode.

The process is this: instead of using a battery of size suited to the total work to be done, a number of small batteries are to be employed, each adapted to doing the work required upon one article or set of objects. All the positive poles may then be connected to one anode, or a number of plates, distributed about the solution, but acting as a single anode; the negative wires are to be attached separately to the objects upon which each is intended to direct the current, which then, by the ordinary means of resistance and galvanometers, may be controlled and measured. An extension of this principle will be found, § 381, applied to the purpose of controlling the state of the solution and the process, in depositing alloys.

345. **Depositing Apparatus.**—It is desirable to provide a means of connecting and arranging the objects without trusting to mere wires, which are also troublesome, and apt to get in contact or to be disturbed. When square vessels are used this is easily effected by having bars of brass across, with a clamp at one end to grip the vessel. Fig. 70 shows the inner angle of a frame which I have found very convenient for the arranging of objects. A is a bar of hard wood with three mortises cut into its end to receive the three flat bars of wood 1, 2, 3; the lower side of 1 and the upper side of 2 are faced with strips of stout sheet brass, or copper silvered, and these are connected to the binding screw + by turning the ends

Fig. 70.



up outside A. The other end of the frame is exactly similar, except that the lower side of No. 2, and the upper one of 3, are faced or connected to the − binding screw; thus at the end shown, *a* is a metal-lined opening, having an unlined opening corresponding to it at the other end of the frame, while the opening *b* is unlined, and its corresponding one at the other end lined. Metal rods passing through these openings are therefore in connection, the upper ones with the + and the lower ones with the − pole of the battery. B is such a rod, the end flattened out and formed into a spring, which presses upon the plates and allows the rod to be placed as desired by means of the projecting end. The anode plates are hung upon the upper rods and distributed as required, and the objects are slung by wires from the lower, or − rods, which are connected to the zinc of the battery.

This frame can be placed over any vessel if provided with a support, and can be lifted up slightly, and moved about occasionally, to disturb the liquid, or even may be kept in constant gentle motion by mechanical means, if these are available.

346. Depositing Solutions.—Before describing the special solutions for use in each case, it will be well to study those general principles applicable to all, the comprehension of which will lead to intelligent and successful working. A perfect solution would be one which contains sufficient metal for rapid working; will give it up freely under the influence of the current; will also freely attack the anode, but only while current passes, so as to keep the quantity in solution uniform; and which has no spontaneous action either upon the metal to be deposited or that on which the deposit is to be effected. All these qualities are rarely combined, but our object is to obtain as many of them as possible. In selecting salts, therefore, we have to consider—

(1) *Chemical Reactions.*—It is *desirable* that the non-metallic radical should have very slight power of attacking the metal, or of forming with it basic salts; thus, sulphate of copper is preferable to nitrate, because sulphuric acid does not act on copper except when aided by extraneous energy, as when the current passes. But it is *essential* that this radical should have little or no tendency to combine with the metal on which deposit is to take place, because this will be sure to prevent adhesion; thus it is impossible to deposit copper direct upon iron from the sulphate of copper, because the sulphuric radical tends to combine with the iron.

(2) *Solubility.*—This has two bearings—quantity and rapidity of solution; as a salt may dissolve abundantly and yet slowly; or the liquid may rapidly become saturated, and yet very little be dissolved. Thus, sulphate of copper dissolves freely enough as to quantity, as the solution contains 30 per cent. of the salt, but it

dissolves slowly, and the consequence is that as fresh salt forms at the anode it is very apt to crystallize there instead of dissolving, so that it is necessary to have sufficient free water present to prevent this.

Under this head also has to be considered the necessity for the presence of some free solvent besides the salt itself. Thus, in copper depositing, free sulphuric acid helps greatly; and in silver depositing, the presence of free cyanide of potassium is essential to dissolve the cyanide of silver as it forms.

(3) *Electric Resistance, or Conductivity.*—Of two or more solutions otherwise equally satisfactory, one may be a much better conductor than others, and the importance of this is that it requires fewer cells in series to work it, and therefore costs so much less. It is from this point of view also we must consider chiefly the effect of other substances in the solutions besides those taking part in the chemical action—viz. the metallic salt and the excess of the solvent. As a general rule, such bodies do harm rather than good, for which reasons all formulæ should be regarded with distrust which load the solutions with chlorides, or sulphates, or carbonates of the alkalies.

347. COPPERING SOLUTIONS.—(1) For all ordinary purposes, that is for depositing upon *non-metallic objects*, upon *copper*, *brass*, *German silver*, and *lead*, the best possible solution is that already mentioned: saturated solution of sulphate of copper diluted with one-fourth of water containing one-tenth by measure of sulphuric acid.

(2) *Iron, zinc, pewter, and Britannia metal* require an alkaline solution. The one commonly used is cyanide of copper dissolved in cyanide of potassium. It may be made by the battery process, which is also available for silver and gold. A large sheet of the metal connected to the + pole of a battery is suspended in a solution of cyanide of potassium of suitable strength (three-quarters of an ounce to the pint), a small plate is attached to the negative pole and suspended in a porous cell in the same solution, and the battery worked until deposit forms on this latter. This plan is convenient for lazy people, but it leaves free potash in the solution, which takes up carbonic acid from the air. The best plan is to throw down a neutral solution of sulphate of copper with cyanide of potassium as long as a precipitate forms. This should be washed several times, and dissolved in cyanide of potassium.

This solution requires to be kept at a temperature of 100° to 150° Fahr., and to be worked with a battery powerful enough to give gas off freely at the cathode or object. About 2 Groves, 4 Daniells, or 6 to 8 Smees, in series, will do this, their size being regulated according to that of the object.

(3) *Watt's Solution.*—Carbonate of potash, 4 oz.; sulphate of copper, 2 oz.; liquid ammonia, 2 oz.; cyanide of potassium, 6 oz.; water, about 1 gall. Dissolve the sulphate of copper in boiling distilled or rain-water, and, when cold, add the carbonate of potassium and ammonia. The precipitate formed is redissolved. Now add the cyanide of potassium until all blue colour disappears.

(4) *The best Solution.*—This I have modified from the foregoing, chiefly by omitting the carbonate of potash, which is unnecessary. Per pint of solution the quantities are about: Sulphate of copper, ¼ oz.; liquid ammonia, ¼ oz.; cyanide of potassium, ¾ oz. But the simplest directions are: Dissolve ¼ oz. of sulphate of copper for every pint of water; add ammonia till all precipitate is redissolved, forming a deep blue solution; then add solution of cyanide of potassium till this colour quite disappears; add ammonia and cyanide whenever required to keep the solution in good order. When these are deficient, the anode coats itself with a blue powder. This solution requires the same battery power as the cyanide one; it must be worked also so as to give off gas, but the advantage of it is that it works freely when cold.

As these solutions are expensive to work, they should be used only to form a perfect film of copper. The work is then to be completed in the ordinary acid bath; but great care must be taken in effecting the change to wash off every particle of solution, and to dip the object in acid before putting it in the acid bath, otherwise the second deposit will not adhere to the first. If ammonia is in excess, copper may not deposit, or, more strictly, it is redissolved at once. If the solution is too rich in copper, the metal may come down as a powder: the deposit is in fact a compromise between copper and hydrogen, and it is necessary to attain the happy medium at which good adherent metal is produced.

348. Depositing the Copper. — Copper may be deposited by what is called the single-cell process, which is simply arranging the object as the negative metal of a Daniell's cell, as to which see p. 97. A battery and separate vessel is far the best plan. The cell being arranged with the anode connected, and the object being perfectly clean, it should be connected to the zinc of the battery, and immersed without exposure to the air, if adherence is required; if a removable deposit is wanted, then the precautions must be taken mentioned § 321. It is better to use a rather strong battery at first, to secure deposit all over the surface; after a few minutes the object should be examined without removal, and a soft brush may be passed all over it, especially into hollows, to remove any air bubbles. For non-metallic objects, it is often better to insert them without a regular anode at first, and to guide the deposit to the deepest hollows and points most distant from the connection by

holding near them a wire, or small strip of copper, as the anode, till a general coating is secured. Objects should not be disconnected, or removed from the solution; but if a very thick deposit is wanted, it will be requisite to remove the object occasionally, and file away the nodules and irregularities which always form. In all cases of removal, even for a minute, the same precautions must be taken as at first immersion to secure a perfectly clean surface, and the best plan is to dip into weak nitric acid, and instantly place in the bath. Even a minute's exposure to the air suffices to form a slight brownish film of oxide, which, though scarcely visible, effectually destroys the coherence of the deposit.

349. REMOVING THE DEPOSIT.—When a sufficient thickness has been secured, the object is to be taken out, washed, and allowed to dry, and if it is to be removed (as from a model) all excrescences and overlapping crystals (which are generally rather brittle) must be carefully removed, one edge gently detached, and the coating stripped off when its form permits; in some cases of deposits upon metals this is difficult, but will be facilitated by holding the object over a flame or placing it on a hot iron, heating the deposit most. The deposit has at first an extremely rich colour, which would be a most valuable aid to ornamentation if it could be preserved, but unfortunately its endurance is very slight, and a few hours in the air destroys its beauty. For most purposes, therefore, when the surface is to be preserved, not to be used, it has to be prepared by some means of colouring.

350. BRONZING.—*Brown.*—This is produced by a suboxide of copper, obtained of various shades: (1) Moisten with water, to a wineglass of which five or six drops of nitric acid are added, allow it to dry, and then heat till the desired shade is obtained. (2) Rub well in and cover with finely-powdered peroxide of iron (jewellers' rouge or red hematite ore); heat till nearly red. (3) Darker shades may be obtained by mixing the peroxide of iron with blacklead, ground to a fine paste with spirits of wine. The copper is to be covered with this paste, and heated till too hot to hold, then brushed well. When the colour is obtained, the objects should be warmed and polished with a cloth, which contains a little beeswax, and all excess of this removed with a clean cloth. A very good effect is also obtained by first bronzing to a deep colour and then lightening the projecting parts by touching with a piece of leather moistened with ammonia.

Black may be produced by polishing with plumbago or by dipping in a weak solution of chloride of platinum: both these require lacquering afterwards. A beautiful dark bronzing is produced by dipping in a weak solution of sulphide of ammonium or of potassium, drying and polishing with an oiled or waxed cloth.

Green is easily produced by putting a little chloride of lime in a saucer, hanging the object over it, and covering with a shade till the desired effect is obtained.

Verd Antique, for busts, &c.—Sal-ammoniac, 8 parts; sea-salt, 8 parts; liquid ammonia, 15 parts; white vinegar, 500 parts. Brush over with this solution several times and allow to dry slowly. There are many other processes, but the foregoing are the most simple and effective.

351. CYANIDE OF POTASSIUM.—The commercial article varies so greatly in quality, that it is almost useless to give quantities for use. There are two sorts, the white which is commonly used, and the black which is the best. The white cannot contain more than 75 to 80 per cent. of the pure cyanide, the rest being cyanate of potash necessarily produced in the reaction; but, according to the impurities of the materials used, and the care taken in making, it may contain as little as 50 per cent. Indeed, I have purchased cyanide containing only 50 per cent. from some of the first houses. It is so easily prepared that it is better to do so than to buy it. It is prepared from ferrocyanide of potassium (yellow prussiate of potash) and carbonate of potash, the latter of which is the common source of impurities, of which sulphate of potash is the most important, as it is not only useless, but destroys also its equivalent of the cyanide first produced. The ferrocyanide is to be crushed and dried very thoroughly upon a heated iron plate till the water of crystallization is driven off and a perfectly white powder produced, of which eight parts are to be taken by weight to three parts of carbonate of potash similarly dried. These proportions give one equivalent of cyanate of potash to five of cyanide, and form the white product. By adding 1½ part of finely-powdered charcoal the whole is converted into cyanide, and the product is black through a remaining excess of carbon. An iron crucible or pot, carefully freed from any rust, is heated to a low red, and the materials (very thoroughly mixed and still warm) are inserted by degrees and brought to perfect fusion, in which they should be kept for twenty minutes, stirring occasionally but kept covered at other times; the stirring is effected with an iron rod, which is to be examined; the coating it brings away is at first brownish, at last becoming a clear porcelain white, when the operation is complete. This gradation of colour cannot be observed when charcoal is used, but the diminution in the gas given off by the fused liquid, which should be kept at a just visible red, will indicate the completion of the reaction. The pot should then be removed, allowed to stand a minute or two for the iron to settle, and the clear liquid poured off upon an iron slab, broken up and bottled tightly while warm, as it is deliquescent and deteriorates by absorbing carbonic

acid from the air. The residuary iron and cyanide should be scraped out while hot and placed in water, and the solution filtered off for immediate use in precipitations, &c. N.B.—It is one of the deadliest of poisons. It will not keep in solution.

352. **Test for free Cyanide.**—It is very convenient to have the means of ascertaining at any time the exact quantity of free cyanide in any solution, and the percentage of the real substance in any sample. I have, therefore, devised a system based upon the ordinary decimal measures obtainable anywhere, and upon the basis of one ounce of cyanide per gallon of solution; from one to two ounces being the proper working strength. One ounce per gallon is equal to 62·216 grains in 10,000; the equivalent of cyanide of potassium is 65, and it takes two of these to precipitate and redissolve cyanide of silver from the nitrate of silver, the equivalent of which is 170. The test solution, therefore, is prepared from pure nitrate of silver, 40·18 grains dissolved in a 10,000-grain flask of distilled water; 4·02 grammes in a litre make the same solution, which is equivalent, bulk for bulk, to a solution of one ounce of cyanide in a gallon, and may be used with any measure whatever, properly divided. I prefer to take 1000 grains of it and make it up to 10,000 again; to take 100 grains of the solution to be tested, by means of a graduated pipette, and then add this weaker solution to it from an ordinary alkalimeter. As soon as the precipitate ceases to redissolve on shaking, the test is complete. A slight cloudiness in the liquid marks this point.

To test a sample of cyanide dissolve 62¼ grains in the 10,000-grain flask and treat this in the same way. Thus, if a sample is so treated, 100 grains placed in a small flask or bottle, 1000 grains of the test put in an alkalimeter and dropped into the flask as long as the precipitate disappears, and upon adding 520 grains in this way a permanent faint cloudiness is produced, the sample contains 52 per cent. of real cyanide. If the original test solution is preferred, 1000 grains of that to be tested must be used, and the result is the same.

353. **Test for Silver and Gold in Solution.**—This can be ascertained by the quantity of cyanide necessary to redissolve a precipitate; but as cyanide does not keep in solution the test must be prepared when required. Make a solution, and test its value as pure cyanide as just described. Take a measure of the solution to be tested, and throw down the metals with sulphuric acid, washing the precipitate till all acid is removed; add the cyanide solution from a graduated vessel, stirring, till all is redissolved. Calculate the quantity used as grains of pure cyanide, and every 65 grains indicate 108 of silver or 197 of gold, but not correctly in old solutions owing to the other metals present. A known measure of the

cyanide solution in excess of what is needed to dissolve the precipitate may be used, and the excess measured by the process for free cyanide and deducted from the measure used; it is more easy to hit the exact quantity by this means.

354. **Silver Solution.**—There are many different formulæ given in various books, and many have been patented, but as there is only one which is really satisfactory, I shall give only a few words to the others. Some recommend the use of ferrocyanide of potassium instead of the cyanide as a solvent; it is no economy, and the solution renders the silver very liable to strip. Hyposulphite of silver in hyposulphite of soda quickly spoils by the action of light. Chloride of silver in chloride of sodium deposits a chalk-like coating useful for some purposes; it answers well for clock and other dials, and may be applied by simply rubbing on and well washing, just as well as with a battery for this purpose; it has no advantage as a solution for use in the battery process. All the processes which involve the dissolving of oxide, carbonate, or chloride of silver are bad; they waste materials and load the solution with salts of potassium much better absent. Cyanide of silver dissolved in cyanide of potassium is the only solution which can be recommended. It may be and is commonly prepared by making a solution of cyanide of potassium of the desired strength ($\frac{3}{4}$ oz. to the pint), hanging in it sheets of silver connected to the positive pole of a battery, and inserting a porous cell, containing the same solution and a copper or iron plate connected to the negative pole. If current is passed until a deposit forms on this latter plate, the solution will be of proper working strength. The only advantage of this process is the saving of a little trouble, but it leaves in the solution an equivalent of caustic potash, which absorbs carbonic acid and so loads the solution with an unnecessary salt which does at least no good. The best way is to prepare the solution chemically.

Silver Nitrate is readily prepared by dissolving in nitric acid; the latter varies so in strength that it is useless to give quantities; the solution is aided by moderate warmth. Commercial silver with copper present answers perfectly, and it is not necessary to crystallize if the excess of acid is carefully neutralized with carbonate of soda; it is best, however, to buy crystallized nitrate of silver, which can be bought for little more than the value of the silver it contains, as it is a by-product in several large operations.

Silver Cyanide.—A weak solution of silver nitrate is prepared, and solution of cyanide of potassium very carefully added as long as a white precipitate forms. It is even better to pass hydrocyanic acid into the solution, but as this (prussic acid) is so deadly a gas, the greatest care is necessary, and the operation ought to be effected in the open air. This process, which is the same as is described

(§ 365) for recovering spoilt solutions, throws down the cyanide of silver without any risk of wasting silver. When all the silver is precipitated, the solution should be vigorously stirred or shaken, and allowed to settle, the liquid poured off, and the precipitate washed, and solution of cyanide of potassium added, and stirred up till it is dissolved; it is then diluted to the required strength, and the proper quantity of free cyanide added. The precipitate should never be dried, as this alters its properties, and it will no longer make a good solution. After solution it may be crystallized as the double cyanide of silver and potassium, if desired; this makes a good solution at any time.

Strength of Solution.—About 2 oz. or 3 oz. of silver to the gallon is a good working strength. As the ounce of silver is 480 grains, and that of nitrate 435½, 164 grains of crystallized nitrate of silver to the pint will give a solution equal to 2 oz. of silver per gallon. Strong solution will work more quickly than weaker ones if ample battery power is used, but they require much more care in working to get a good result. The free cyanide should be equal to about half the weight of silver in solution. With less, the solution conducts badly; with more, it is apt to dissolve off silver from both anode and objects.

355. SILVER DEPOSITING.—An experiment devised for lecture purposes some years ago, exhibits in so striking a manner the fundamental principles of electro-deposition that I cannot do better than describe it, and invite readers to repeat it for their own instruction. Take a clear glass vessel of some width, and cut a strip of wood to go across the top; prepare three narrow strips of copper, as long as the vessel is deep, and fit wires to them; fix one in the middle of the bar of wood, and the others (whose wires are to be long enough to reach to a battery, and allow the bar to be moved about) one on each side, as far apart as the vessel allows, all three being in one plane, but not touching; fill the vessel with a good silver solution; connect the outer plates to a strong battery—one Grove or bichromate, or four Smees will do—and then steadily lower the plates in, watching them with a strong light upon them. One remains unaffected, the middle one takes a bluish tint, the third becomes, as by a flash, a dead white.

The middle one acts chemically on the solution, is partly dissolved itself, and precipitates on its surface a film of silver, through which the copper is visible, giving the peculiar colour; no length of time will greatly thicken this deposit; but if, after a time, it is connected to the battery and regularly coated, in all likelihood the deposit will blister or strip under the burnisher. The plate connected to the zinc of the battery receives a true electric deposit, which under good conditions is so rapid as to produce at once the dead white or "mat" silver. The plate connected to the positive pole has, by the electric tension generated, been changed in its electro-polar relation to the liquid, the silver sides of the molecules are turned from it, and the action of the cyanogen radicals is exalted; it, therefore, dissolves more rapidly than under chemical affinity alone, and it can no longer precipitate the silver; or, at least, if any such chemical deposit does still occur (which can neither be proved nor disproved), the silver so thrown down chemically is instantly redissolved electrically.

It is evident, then, that objects to be coated should be connected to the battery *before immersion.*

356. Now take a strip of copper and one of silver, connect them to a delicate galvanometer, and plunge them into the solution; it will be found that a considerable current is generated; this teaches us that we should never *commence* the deposit in a vessel in which objects already coated are at work, because any combination will generate its own current, quite regardless of all other currents passing in the same vessel, and thus a current will pass between the new object and those already coated, notwithstanding that both are alike connected to the same pole of a separate battery. If one bath is employed, a separate battery should be used, both + poles connected to the same anode if we please, but the new object connected by itself to the zinc of one battery, until coated, when it may be transferred to the other connections.

357. The proper plan is to have one large bath, in which nothing shall be inserted but articles already silvered; by this means it is kept from being contaminated with the base metals. Other smaller quantities of solution should be kept for giving the first coat, and made suitable for the different metals, for a good deposit cannot be obtained upon Britannia metal and the other pewters from a solution in which copper has been plated; they also require much more free cyanide of potassium than copper, brass, or German silver do; all these may be coated in the same bath, but not together.

358. The first deposit, especially with the baser metals, requires to be effected under greater *tension* than ordinary working, but not with too large a current—that is, too quickly. The way to effect this is to employ a powerful battery of small cells, and to use only a small anode, so as to secure high tension at the plates by means of the high electro-motive force of the battery, and considerable resistance in the depositing cell, on the principles described, § 339. The tension must not be such as to give off gas.

359. In any case, after the first deposit is perfected, the object ought to be removed, washed, and well scratch-brushed, to see that the deposit is perfectly adherent, as it is more pleasant to strip it and start afresh then (if necessary) than after the whole operation is

supposed to be completed. When a thick coat is to be put on, and especially if there are ornamental edges and points, it is well to examine now and then, and if any nodules or roughnesses are forming, to file or work them off, perfectly cleaning the article before replacing. Objects should on no account be touched with the dry hand, but kept under water containing a little soda or potash, or cyanide of potassium, and handled only with perfectly clean hands.

360. Another interesting experiment will illustrate the precautions necessary to observe with objects, and also that peculiar state of the liquid which is called *polarization*, and which is the primary condition of electric transmission. Suspend two plates, connected with a battery, as far apart as the vessel allows, or, say 6 inches or 8 inches; in the centre of two plates of copper, an inch or so square, punch holes, and rivet them firmly on the ends of a stout wire. Now suspend this arrangement in the liquid between the plates, but not touching either, and having no metallic connection with the battery, but isolated in the liquid. After a little time it will be found that the end facing the anode is well coated with deposited metal, while the other end has evidently been dissolved; the intermediate wire will share these two conditions up to the middle, but the principal action will be on the ends. The system has been, in fact, polarized in the same manner as cylinders are, in static electricity, when approached to a conductor, and the action is distributed in exactly the same way as a static charge would have been, in the opposite ratio to the resistance between each particle and the conductor. This shows that objects should never be left in the solution when not being deposited on; if an object accidentally falls from its wire, it should be at once removed and rearranged, for, if left, this effect will be produced upon it.

The effect is not well observed in a silver solution, owing to the chemical action of the copper itself, and it requires a strong current; in a copper solution the action is strikingly visible after a few minutes. The explanation of this action will be found § 233, p. 193.

361. **Anodes.**—These should be sheets of pure silver, around the tank; or in small vessels strips of various sizes may be used, so as to be distributed about the objects as required. They should not be attached to copper wire, which is acted upon, though it is greatly protected by a thick coat of solder over it; they should be soldered to stout iron wire, or to strips of lead, neither of which does the solution act on, and these should have strips of copper, well silvered or gilt at their upper parts, for slinging upon the connections to the battery.

If the anodes become coated with a greyish coating, the solution wants more cyanide. When common silver is used, the anodes in this case turn red or purple, owing to cyanides of copper, &c., forming; but pure silver should be used, so as not to keep adding copper to the solution.

362. **Working the Solution.**—A new solution does not work so well as one in constant use. The carbonic acid of the air acts upon the cyanide of potassium, which therefore requires to be occasionally added; the need for this is indicated when the action becomes sluggish, or the anodes and objects become discoloured. If the objects alone are dark and dirty in appearance, instead of a clear chalk white, or rich cream colour, the current is too strong, and the anodes should be reduced in size, or placed farther away from the particular object, or, if the fault is general, the battery power may be reduced. Experience alone can teach all these details. The temperature should be the average one of 60° to 70° Fahr.; when it is colder, the solutions do not work so well, and, if hotter, less battery power will be required.

After a time, a precipitate usually forms, as a greyish-white flocculent powder, which is easily stirred up, and apt to settle on the articles, the solution should therefore be occasionally filtered. The precipitate is mainly impurity, but in some cases it may contain silver, so that it is as well to collect it, and when worth while, burn it in a crucible, with a little nitrate of potash added.

363. **Bright Deposit.**—Silver from the solution described is deposited of a beautiful dead white or "mat," but it may be deposited with a brilliant surface, as if burnished, by adding bisulphide of carbon to the solution. About an ounce of this is shaken up in a bottle with a pint of strong solution of cyanide of silver, and plenty of free cyanide. This is added occasionally as required, little by little, to the bath. It should not be used on the small scale, as it is offensive and unwholesome; excepting when in regular use, it is also apt to spoil the solution.

364. **Finishing the Work.**—On removal, the object should first be dipped in water containing free cyanide, then rinsed in boiling water, allowed to dry, and placed in sawdust (box or mahogany, not pine). All parts intended to be bright should then be scratch-brushed, either by the lathe or by small hand-brushes; hard hair brushes with fine sand or Bath brick may be used. After this, the surface should be polished with tripoli or rotten-stone, and whiting and rouge, and then burnished with brightly polished steel {or agate burnishers, which are made of various shapes to suit different work; the object should be kept wet with soap-suds while burnishing, or some use stale ale. This is an operation requiring much practice to do it well, and it is in fact a special business. Care should be taken to make the strokes of the burnisher always in the

same direction, or only slightly deviating from it where markings require burnishing down; the strokes should never be crossed.

365. Spoilt Solutions.—From various causes, and chiefly from the gradual accumulation of the salts of potash, resulting from the action of the air upon the free cyanide, the solutions in time become bad: they do not deposit freely metal of good colour, or the deposit tends to strip under the burnisher. It then becomes necessary to recover the metal and make fresh solution. Two processes are commonly recommended: (1) To add acid until all the metal is thrown down, and then melt the precipitate after drying; this process is a dangerous one and must be effected in the open air, as poisonous gases, chiefly prussic acid, are given off. The residue must also be fused by degrees, as the cyanide of silver does not fuse quietly; it is better to reduce it with zinc and a little hydrochloric acid—this also in the open air. (2) Evaporate the solution to dryness and fuse till the silver is reduced, and wash off the cyanide of potassium, which generally carries some of the silver with it.

The plan I recommend has the advantage of economy of materials, and freedom from danger or nuisance. Place the solution in a large flask, fitted with a safety-funnel and delivery-tube, and connect to this by an indiarubber pipe a wide glass tube, which place in another vessel, so that its end dips half an inch or so under a solution of nitrate of silver. Now add sulphuric acid gradually by the safety-funnel, allowing the effervescence to subside, and shaking the flask occasionally; continue adding acid as long as it produces any fresh precipitate. Then, by means of a sand bath, heat the flask and keep the solution boiling as long as a precipitate continues to form in the other vessel. This precipitate is pure cyanide of silver, and only needs dissolving in cyanide of potassium to form the fresh solution. The precipitate in the flask is also cyanide of silver, but not pure, though sufficiently so for use in most cases; if it is preferred it can be reduced by zinc and hydrochloric acid, or dried and fused. This process saves the cyanide of potassium otherwise required to precipitate the silver.

366. The same process is really the best in preparing an original solution, placing, that is, a solution of cyanide of potassium in the flask and distilling over the hydrocyanic acid into the nitrate of silver. We thus avoid any risk of wasting silver, and we get a pure product, for the gas will not precipitate copper or gold in an acid solution. The nitric acid of the silver salt is also saved, and will dissolve a fresh lot of silver, nor is it necessary to crystallize the nitrate, as the free acid is not injurious. If it is not desired to precipitate silver, cyanide of potassium may be obtained by substituting caustic potash in the receiver for the silver salt, but in this

case the tube should not be connected till just before the contents of the flask begin to boil, in order to allow the carbonic acid to be given off; a little prussic acid gas comes off too, and therefore the end of the tube should be led to a chimney, but very little goes over till the liquid boils.

367. GILDING SOLUTION.—There are many formulæ given for dissolving chloride, oxide, or fulminate of gold in cyanide of potassium. These are all troublesome, expensive, and the last dangerous. The best plan is to dissolve cyanide of gold in cyanide of potassium. The strength should be from half to one ounce of gold per gallon, and it may be prepared by the battery process, exactly as described for silver. It is, however, better to prepare the cyanide chemically. Pure fine gold should be used, but it may be obtained from any alloy by dissolving in aqua regia (1 part nitric, and 3 of hydrochloric acid), pouring off the clear liquid and washings of any residue, evaporating off free acid, and precipitating the gold by protosulphate of iron (green vitriol or copperas), of which about five times the weight of the gold should be used. The gold is found (after standing an hour or two) perfectly pure as a dark brown powder. This, or "fine" sheet gold is to be dissolved in aqua regia, as before, and free acid driven off, care being taken that no yellow powder is formed; if it is, by too much heat, a drop or two of acid must be added to redissolve it. This solution should be largely diluted and cyanide of potassium added, as long as any precipitate is formed. This is the cyanide, a lemon yellow powder, which only requires to be separated from the solution, washed, and dissolved in cyanide of potassium. These are the usual instructions, but I advise a little further proceeding to avoid any risk of loss of gold by not hitting the exact point of precipitation. Add a trifle too much cyanide of potassium, so as to ensure complete conversion and redissolving of a little. Filter off the cyanide formed, and to the solution add sulphuric acid till it gives an acid reaction, and filter off after standing for some hours. Even then there is risk of the alkaline salts dissolving some little gold, but this may be recovered by setting the solution aside with some scraps of zinc, which will throw down any gold so dissolved.

In dissolving common gold there is often found a residue which obstinately resists solution, yet retains the form and workmanship of the original article: this is the silver of the alloy formed into a dense chloride.

The chloride of gold solution may, if preferred, be neutralized with caustic soda or potash (not carbonate) until it is decidedly alkaline, and then either cyanide of potassium may be added, or hydrocyanic acid distilled into it to throw down the cyanide of gold. This solution is, however, very apt to retain gold in solution with the residuary alkaline salts. If ammonia is used instead of the fixed alkalies, a precipitate is formed which is fulminate of gold, and must not be dried, as it becomes violently explosive.

368. **Spoilt Solutions.**—These should be treated as described for silver, but the resulting cyanide, which will probably contain other metals, should be dried, mixed with its weight of litharge, and fused. The residue, after washing, is placed in excess of nitric acid, which will dissolve out the lead, &c., and leave the gold pure.

369. **Gilding.**—This process is much more rapid than any of the others, as a few minutes is usually enough to give a good deposit; this is due to the high equivalent 197, so that the same current deposits nearly twice as much as it would of silver, and more than six times as much as it would of copper. Gold has also very great covering properties, and a much thinner film gives a better appearance and protection than a similar thickness of other metals would. The usual difficulty indeed is that the work is done too fast. Small battery power is needed, a single Smee having sufficient force. The solution is to be heated in a glass or enamelled iron vessel to 130°—180° Fahr. The warmer the solution the darker the colour of the gold, which is to be controlled by regulating the battery power and the heat. The anode should have the same surface as the object, and should be fine gold; the object should be kept in constant motion, and if the colour is too dark, its distance from the anode increased.

When the solution is to be set aside, water should be added to replace that evaporated off by the heat; at the same time free cyanide, if needed, should be added; there should be enough to keep the anode clean and maintain the quantity of gold in solution, but too much gives a bad colour to the gold, and redissolves the metal while it is depositing.

Small objects may be gilt together in numbers by putting into an earthenware basket with a connecting wire to some of them, and shaking about in the solution, so as to expose fresh surfaces continually.

370. *Finishing* is effected precisely as described for silver.

Colouring.—If the colour is bad it may be made rich by the following mixture: One part each of alum, sulphate of zinc, and common salt, and two parts of saltpetre are mixed in water into a paste, which is to be smeared over the articles, which are then placed on an iron plate upon a clear fire, heated, and thrown into cold water. A bad colour in silver may be remedied with borax applied and similarly treated till it fuses. Articles united with soft solder cannot be treated by these processes.

371. **Plating Iron and Steel.**—For some reason, difficult to understand, it is impossible to obtain an adherent coating of either

silver or gold directly upon iron or steel, no matter how perfectly the surface may have been cleaned. It is, therefore, customary to deposit first a mere film of copper from an alkaline solution, as previously described. A film of mercury would have advantages over that of copper, for the same reasons that such a film is frequently used upon even copper or brass to secure a more perfect union between the metals. But iron resists the union with mercury as well as with silver and gold, and it is very difficult to coat its surface with a perfectly even homogeneous amalgam, though many processes have been suggested and said to be successful. That which I have found best consists of a mixture in equivalent proportions of the nitrates of silver and mercury, in quantities represented by about 50 gr. of each metal to a pint of solution. The metals are to be separately dissolved in just sufficient nitric acid, the mercury in dilute and cold acid, and then mixed, sufficient free nitric acid being kept in the solution to feebly act upon iron when plunged in it. The metal leaves this solution covered with a dark powder, which, on lightly brushing under water, gives place to a bright surface. The object should be at once placed in the silvering solution, and, when a coating is seen to be formed, it should be removed, washed, dried, and heated to about 400° Fahr.: its surface should be then scratch-brushed, and the article replaced in the silvering solution till a sufficient coating has been deposited. Iron and steel may also be amalgamated by rubbing with sodium amalgam after well cleaning, and may then be plated in the same way as other metals.

372. NICKEL PLATING.—This process has come into much use in the last few years, and, unless arrested by the great advance in the price of nickel which it has caused, it bids fair to be very largely employed for many articles in common use. There is, however, much misconception as to the purpose and advantages of a coat of nickel. It takes a very brilliant polish of a bluish tint, and the hardness of the metal enables it to retain that polish much longer than silver does; then, unlike silver, it is not affected by sulphuretted hydrogen, and therefore does not blacken with the gases given off from burning coal or gas; it is, therefore, admirably adapted for such purposes as shop-fittings, and particularly scales and weights, which would merely require to be washed or wiped in order to keep them clean; and for window-frames and door-plates, which would long retain their beauty with little labour. But it is often stated that nickel resists acids, and this is not the case, for all the ordinary acids dissolve it freely; it is, therefore, not suited for instruments to be used in chemical laboratories, or where acid fumes prevail; nor is it adapted for lining to vessels used for cookery, as silver is.

373. *Nickel Solution.*—Nickel may be deposited from almost any

of its solutions, but the statement commonly made in the books that it is very easily deposited, is a very long way from the truth. The most convenient and manageable solutions are those in which a double salt of the metal and of an alkali is present, such as the double sulphate or chloride of nickel and ammonium, potassium, or sodium, or even magnesium. Cyanide of nickel dissolved in cyanide of potassium will also work well, and probably deposit more quickly than the others, but is, of course, more expensive, and has no advantages to compensate, and I shall speak only of the double sulphate of nickel and ammonia. Crude nickel is obtained in small, irregular fragments as reduced by the common process, and this dissolves freely in dilute sulphuric acid, and crystallizes out as sulphate $NiSO_4 + 7H_2O$ $155 + 126 = 281$, green rhombic prisms containing 7 atoms of water. Sulphate of ammonia $(NH_4)_2\ SO_4 = 132$· has the property of replacing one of these atoms of water and forming the double crystal $NiSO_4\ (NH_4)_2\ SO_4 + 6\,H_2O = 395$, a saturated solution of which, with a little water added to diminish the tendency to crystallize, is the solution to be employed. It is, of course, not necessary to crystallize the double salt at all, as the solution can be at once formed by dissolving the two sulphates in the proportions given.

A fair depositing solution may also be made by passing a strong current from a nickel anode into a solution of ammonium chloride (sal ammoniac) until the metal begins to deposit upon a plate within a porous cell, in the same manner as is described for other solutions.

374. DEPOSITING NICKEL.—The real difficulty lies, not in the selection of a solution, but in the management of the operation, for nickel is different from any of the ordinary metals hitherto described, in that its deposit is always accompanied by a considerable evolution of hydrogen gas; this is, of course, pure waste of power, and the object to be aimed at is to get as little gas and as much nickel as possible. Another consequence is, that the deposit is apt to contain gas, and therefore to be porous or flaky, in which case the coating will be apt (as soon as it reaches a moderate thickness) to split and curl up, and separate in brilliant films. To prevent this, the solution should be strong, and the battery power carefully adjusted to the work doing. A powerful battery is required at first starting, such as two or three Bunsens in series, but as soon as a complete coating is obtained, economy and good working both require less force to be exerted; for the main deposit a single Smee cell is sufficient, but its size must correspond to that of the objects to be coated, and the resistance of the depositing cell must be controlled by means of ample anode surface, fully as large as the objects. The solution must be kept neutral or slightly alkaline by addition of

ammonia when necessary; the tendency of all ammoniacal salts is to become acid by losing ammonia, and any free acid thus produced prevents metal from depositing, or redissolves it in the act of depositing, giving off hydrogen in its place.

The great difficulty in the way of nickel plating in the small way by amateurs, to whom it would be very useful, is that it is almost impossible to obtain the necessary anode: it is sometimes stated that a platinum anode will answer; but this is not the case, as that means complete decomposition of the solution and the setting free of an equivalent of acid, besides which, it would require the constant renewal of the solution.

Sulphate of nickel may be used in a single cell process exactly as in the case of copper, but it is an exceedingly wasteful plan, as the nickel salt passes through the porous cell, and is reduced upon the zinc plate, just as copper is.

The surface of the nickel deposit, when good, presents a very peculiar appearance; it is not bright—a bright deposit will usually peel off—but of a dull yellowish colour; after removal and washing it has to be worked up to brightness by the usual processes of polishing.

The following particulars of apparatus on the factory scale may prove useful:

The *depositing cell* contains about 70 gallons of liquid, in which the double sulphate is dissolved at the rate of three-quarters of a pound per gallon: it is a wooden tank, lined with asphaltum cement, 5 feet 6 inches long, 2 feet wide, and 14 inches deep.

The *battery* is a cell containing about 10 gallons of liquid, which is a very dilute sulphuric acid (20 ounces to the charge is named), fitted with six amalgamated zinc plates 9 × 10 inches, with six equal sized carbon plates arranged alternately between the zincs.

About 6 inches square of anode surface is used per gallon of solution, and the anode surface is always kept in excess of that to be plated. In some cases batteries are used consisting of two cells in series, similar to that described, the plates in each cell being connected so as to act as one plate of each kind.

375. IRON DEPOSITING.—Iron has very great chemical resemblances to nickel, and most of the remarks made upon the latter metal apply also to iron. The solutions are corresponding ones, in which iron takes the place of nickel, but owing to the tendency of iron salts to pass into a higher state of oxidation, they spoil rapidly. Hydrogen is given off also, and it would appear that the corresponding oxygen appears at the anode, unites there with the iron, and thus tends to the production of basic salts. For these reasons, in the case of iron, the double chloride of iron and ammonia appears to be more advantageous than the sulphate. To produce

this, dissolve clean iron wire in hydrochloric acid, using heat at the close, and having iron in excess to prevent the formation of perchloride; for every 58 grs. of iron dissolved add 53·5 grs. of ammonium chloride to the solution. I have found that the addition of a proportion of glycerine to the solution diminishes its tendency to spoil. No deposit can be obtained from a solution of a ferric salt; in these the action takes the form of a generation of hydrogen at the cathode, which reduces the salt to the ferrous condition; at the anode, meanwhile, iron is dissolved by the acid set free until a neutral ferrous solution is produced. In consequence of this, an iron solution which is spoilt either by action of the air or by generation of basic salts, may be renovated by adding the proper acid, and, if needed, heating it till it becomes clear, and passing current from an iron anode. Of course, there must also be a proportionate addition of ammonium chloride.

The deposit of iron is likely to have important scientific uses, as in examining the laws of magnetism, but it would not seem likely to have extensive practical application. Its principal utility is likely to be in the same direction in which it has been used for some years—viz. for printing purposes. It has been used to give what is called a "steel face" to copper plates, by depositing on them a thin film of hard crystalline iron which does not seriously affect the fine lines of engraving, but wears much longer than copper, and when defaced, can be dissolved by acids and renewed, without the plate itself being subjected to wear. It takes the ink well also, and will work with some inks, such as vermilion, which are useless with copper. It would probably answer well, also, for facing to ordinary type.

I have been informed, on what I believe to be good authority, that iron deposits beautifully, although accompanied with torrents of gas, with a battery of ten or twelve Bunsens in series, but I have not myself tried anything beyond two or three Smees.

376. Platinum.—This is an exceedingly difficult metal to deposit; in fact, although some writers say that it is to be done, it is very doubtful if a reguline film of tough metal has ever been obtained. The deposit is highly crystalline and brittle at its best, and tends very strongly to pass into the state of black powder. It is commonly stated that a very feeble battery is required, but this is not the case: on the contrary, it requires a force equal to four Smees in series, in order to overcome the great resistance of the liquids, and to compensate for the fact that there is no action on the anode; the platinum, therefore, is wholly derived from the solution, and must be replaced as chloride. A small "current," or rather small density of current, is required in order to prevent undue generation of gas and black deposit. I have found that a "density" of ·2 is the utmost current to be used.

Platinic chloride $PtCl_2$ on the equivalent notation, or $PtCl_4$ on the atomic, is the basis of all the solutions of platinum. Its preparation requires some precautions, as it must not be heated at any time beyond the heat of the water-bath, or a change takes place which is not correctly stated in the text-books. They all say that platinous chloride is produced, which will redissolve in excess of acid. I have found that overheating, even with great excess of acid, turns the solution a dark olive instead of clear yellow (or red, if iridium is present), and that a black powder is formed which cannot be redissolved without drying and heating to red: it may be that this is due to the other metals usually accompanying platinum. Platinum left in a bottle with aqua regia (1 nitric, and 3 hydrochloric acid) will dissolve in time, but the process is a very long one; heating in a water-bath hastens it; it should then be evaporated to dryness in the bath, dissolved in a little water, and if desired left to crystallize. This solution may be used to deposit from, but it requires very great care.

Sodio Platinic Chloride is obtained by adding 1 equivalent of common salt (58·5) to 1 equivalent of platinic chloride (169·5), which corresponds to 98·5 of platinum in solution: it may be crystallized as a yellow salt. This deposits more easily than the chloride.

A still better solution is made by adding to the foregoing about 4 equivalents ($63 \times 4 = 252$) of oxalic acid, and then rendering the solution strongly alkaline with caustic soda. This in fact is the best solution I have tried. A similar one may be made from the yellow precipitate formed by ammonium or potassium chloride with platinic chloride. These precipitates are soluble in oxalic acid (a fact not noticed in the text-books so far as I know, or in Storer's dictionary of solubilities); more of the acid is required, however, and the ammonia precipitate requires boiling. The sodium form is however preferable, as most stable. From my experiments I am disposed to think that silver, coated with a film of platinum in this solution, would be superior to the ordinary platinized silver for batteries: it would cost more as taking more platinum, but would be far more durable. Its surface is highly granular.

The equivalent of platinum deposited is variable, owing to gas being generated. I have obtained from 44 to 48; theoretically it is 49·3 corresponding to one equivalent of chlorine, owing to all these solutions being of the platinic series.

377. Aluminum.—The depositing of this metal would be a process of great value in the arts. Several such have been published, and some patented, but none is of any practical value. In one case it is stated that a solution of alumina mixed with cyanide of potassium decomposes with six Bunsens or ten Smees. This statement is strictly

true: it does decompose, only, unfortunately, it does not deposit aluminum, but simply gives off hydrogen. I spent a good deal of time and trouble over this, till I satisfied myself that cyanogen will not unite (as a cyanide) with aluminum. In another book (a good one, too) a process is given which is essentially one for obtaining a solution of sulphate or chloride of aluminum, and it is stated that from this a fine white deposit of aluminum can be obtained. It may be so, but all I can say is, I cannot obtain it, nor can I find that anyone has as yet succeeded in effecting a deposit; all the solutions I have tried, acid, neutral, and alkaline, decompose and give off gas, but refuse to deposit metal. I believe, however, that aluminum may be more readily deposited in alloy with other metals, and with great advantage.

Aluminum may be reduced from its chloride by means of electricity, as a source of the metal, however, if the chloride contained in a crucible is kept in fusion by heat while the current passes, a carbon pole with nicks cut into it being used to receive the reduced metal. Aluminum may be obtained from *Cryolite*, a natural double fluoride of aluminum and sodium, by this process.

378. DEPOSITING ALLOYS.—It is supposed by many, and the idea is supported by many indirect statements in the books, that metals deposited by electrolysis are absolutely pure; but this is a great mistake, as far as the principle is concerned. It is true that the current exercises an elective influence when salts of several metals are in company, as explained, § 298; this election depends upon the fact that each chemical compound requires a definite force to break it up, and therefore, as a rule, the one most easily decomposed will deposit its metal in preference to the others; but if the force be sufficient, all will be decomposed, and a mixture of metals will come down. The solution also exerts a selective influence on the materials of the anode; hence pure copper can be obtained in a solution of the sulphate from an impure plate, because the sulphuric acid refuses to dissolve the carbon, lead, tin, &c., which form a dirty coating over the plate after a time, while any zinc and iron passing into solution require so much more force to decompose that they remain in solution; but pure copper would not be so easily obtained from a solution of chloride, nitrate, or acetate, as these would carry over the easily-reducible metals, which would deposit even sooner than the copper.

379. But the object to be attained in depositing alloys is to be able to secure a definite proportion of a given quality, and as to the mode of effecting this very little is really known. The subject is of so much interest and may have so much importance, that I depart from my usual practice of stating nothing that I have not thoroughly tested. In this case I propose to give the particulars

of various solutions patented for depositing brass and bronze, and then to furnish a statement of the principles necessary to be attended to in any attempts to devise solutions and modes of working.

The quantities are proportional, grains or ounces, &c.:

TABLE XXV.—BRASSING SOLUTIONS.

	1	2	3	4	5	6	7	8
Water	5000	5000	1280	50	400	160	10	2000
Copper sulphate	..	..	..	..	..	..	..	..
„ chloride	25	15	..	..	2	..	..	10
„ acetate	..	..	5	10	..	..	..	..
„ cyanide	..	..	..	..	..	2	..	..
Zinc sulphate	48	35	10	..	4	..	..	20
„ acetate	..	..	..	1	..	..	..	..
„ cyanide	..	..	..	..	..	1	..	..
Potassium cyanide ..	12	50	8	*	..	16	1	24
„ carbonate ..	610	500	72	..	50	..	..	160
„ acetate ..	..	..	..	10	..	..	..	..
Ammonia liquid	..	..	40	..	..	..	..	*
„ carbonate ..	..	..	..	..	..	16	1	..
„ nitrate	305	..	..	..	25	..	..	..

* Sufficient to effect the purpose.

1. De Salzede.—Dissolve the cyanide of potassium in 120 parts of the water, then in the remainder dissolve the salts of potash, zinc, copper, and ammonia, raising the heat to about 150° Fahr., adding each salt as the first is dissolved, and stirring well; then mix, and allow to stand a few days.

2. De Salzede, prepared in same way as 1.

Both are worked with brass anode, and a battery of two Bunsen's cells giving a full current.

Bronze may be deposited by substituting chloride of tin for the sulphate of zinc—25 parts in 1, and 12 in 2, working at a temperature not exceeding 97°.

3. Divide the water into two parts, and one of these into four parts, and dissolve the salts. 1, the copper, and add half the ammonia; 2, the zinc, at about 180° Fahr., and the rest of the ammonia; 3, the potash; 4, the cyanide of potassium in hot water. Then mix 1 and 2, and add 3 and then 4, stirring well; then add the remaining half of the water.

Work with brass anode and full battery power, adding ammonia and cyanide of potassium when required.

4. Russell and Woolrich.—Dissolve the salts, and add suffi-

cient cyanide of potassium to redissolve the precipitate formed and be somewhat in excess. Worked with brass anode.

5. Dissolve separately and mix.

6. Dissolve and mix, adding the cyanide last.

7. This is to be prepared by the battery process, the solution being made and kept at 150°. A large brass anode and a small cathode are connected to a battery, and current passed till the solution deposits freely.

8. Brunell.—Dissolve separately, mix the copper and zinc solutions each with part of the potash, then with ammonia enough to redissolve all precipitate, and add the cyanide solution. To be worked with large brass anode and two or more Bunsen's cells, adding ammonia and cyanide as required.

It is stated by Watts that the solutions 3, 7, and 8, containing ammonia, work the best, because they dissolve the zinc from the anode more freely; and that whenever a white deposit forms on the anode, free ammonia should be added.

No. 6, which is Morris and Johnson's, is spoken of very highly by some as giving good deposits capable of varying proportions. It is to be worked hot, and requires strong battery power, giving off abundant gas while working.

380. *Principles.*—(1) The object to be attained is the deposit of definite proportionate weights of two or more metals; but as the current knows nothing about weights, but measures its work by equivalents, the proportions by weight desired must be reduced to equivalent proportions, by dividing the weight by the electric equivalent given in the table, p. 212. Thus, a brass is required containing 64 copper to 36 zinc; $64 \div 31 \cdot 75 = 2 \cdot 02$ and $36 \div 32 \cdot 6 = 1 \cdot 08$ gives the proportion in which the current must divide itself between the salts of copper and zinc.

(2) The solution need not contain the two metals in either of the two proportions, weight, or equivalent; the relative degree can have no fixed law, as it must depend on several conditions, and mainly upon a combined consideration of the facility with which the two salts decompose, and the equivalent proportion required to be decomposed.

(3) Incompatible salts cannot be joined in one solution, that is to say, salts which exchange their constituents or throw down a portion as insoluble, unless another ingredient is to be added which will redissolve the precipitate; this latter is often the case when ammonia or cyanide of potassium is to be added, more especially ammonia. In such cases, however, it must be ascertained that these new conditions do not alter the relative conductivity or decomposability of the various metals in solution.

(4) It is of the utmost importance that the metals of which the

alloy consists should not have any strong electric relations to each other in the solution to be used. It must be remembered that what is called the electric order of metals is a pure delusion, unless taken in a particular solution, § 267, for a metal may be positive to another metal in one solution and negative to it in another, as this depends on the relative affinities of the metals to the other radicals.

(5) It is *desirable* that the several salts should have nearly the same electric resistance (§ 232), or that these resistances (which partly depend upon the quantity of each salt dissolved) should be proportioned to the relative currents required (see 1); but this is not essential.

(6) It is *essential* that the battery power be balanced against the decomposability of the several salts. This is distinct from their resistance. Each chemical combination needs a fixed force to decompose it, and this is effected by maintaining a sufficient electric tension at the plates to effect it. This may be called the *specific molecular resistance*, set up at the cathode only, while the electric resistance lies in the space between the plates. If there is a great difference between the specific molecular resistance of the different salts, the current will tend to reduce the lowest only, and that perhaps in a powdery state; in such cases the only remedy is to have only a sufficiency of the weaker salt present to supply the required deposit, thus forcing the current to act sufficiently upon the more resisting salt. See § 295, p. 255.

381. Practical Suggestions.—There is only one mode of satisfactorily examining all these points, and this is to test each one by means of a galvanometer which will measure the actions on a definite system. Vessels of the same size should be used for comparing different solutions, and plates of the different metals and also of the desired alloy provided, all of exactly the same size, such as a square inch or 1 × 2, with such an arrangement as will ensure always the same distance between them; then, to ascertain if the condition 4 is fulfilled, the two metals are connected to the galvanometer as if they were battery-plates, to see if a current of notable amount is set up. The same arrangement tests condition 5 by using two plates of the same metal as the solution; the greater the resistance, the less current will pass from a constant battery. Condition 6 can be tested at the same time by observing how many cells of the battery are required to force a given current through, but this test will be only approximate as the resistance affects it; still, it will give practical information.

Care must be taken that there is sufficient free solvent and also water to freely dissolve the anode and keep it clean, as sometimes one metal will dissolve more readily than the other. This, as well as other points, will be ascertained in the experimental vessel by testing with separate anodes of the various metals; they ought all to allow the same current to pass under the same conditions, because this depends wholly on the action of the anode.

It will be observed that the object in these experiments is to isolate and vary one particular fact at a time and measure its influence.

The anode should usually be of the kind to be deposited, so as to maintain the solution uniform. But it may be desirable to use several plates of the separate metals. Here, I think, may be found a principle in alloy depositing which has not yet been employed—viz. to use a separate battery for each anode, so as to vary the force exerted on each metal as necessary; by this means both conditions may be controlled, exactly the proper proportions of each metal may be forced into the solution, and the required tension may be exerted upon each. It is true that the metals are not transferred by the current itself, and therefore the different currents will not select at the cathode their own particular metal, but a sufficient electric force for each will be present at the cathode, and the due utilizing of it must be provided for by attention to the other conditions explained. A similar result may be attained with one battery sufficiently powerful, by leading separate connections from the positive pole to each anode, and interposing resistances so as to control the current to each; but distinct batteries would be best. Of course, all the negative poles would go to the object to be deposited on, the cathode; it would also be desirable to have a galvanometer in the circuit of each anode to secure accuracy.

CHAPTER XI.

LIGHTNING AND LIGHTNING CONDUCTORS.

382. The common conception of lightning may almost be described as a belief that there is something packed away in the clouds, which at some uncertain moment falls from them as a "thunder-bolt," or rushes out upon the earth as a discharge of "electric fluid," with destructive effects, resembling in some degree those of the bursting of a reservoir of water. The conductor is regarded as having some *attraction* for the "bolt," and also as a pipe to receive and carry off the fluid. These ideas are not only erroneous scientifically, but they are the source of many practical mistakes in the setting up of conductors, which sometimes lead to fatal results.

Those who have comprehended the principles of static electricity explained in Chapter II., will see that they are applicable to the present subject, as lightning is strictly analogous to the artificial electric discharge. They will at once understand that the discharge does not merely issue from the clouds and rush to the earth, but that the latter fulfils a function just as important as that of the clouds; the latter are indeed the "prime conductors" of Nature's great electrical machine, but the force is distributed over a vast "inductive circuit," of which the air and the earth form as much a part as the clouds themselves, and the discharge is a redistribution of force all over this inductive circuit, not across the air simply.

383. The thunder-cloud is in fact to all intents a condenser plate upon which terminates the polarized chain of a circuit, and there are two varieties of thunder-storm, which depend upon the nature of the opposite condensing plate. This may be another cloud above, or at a distance from the first; then the discharges occur between the clouds themselves, and the only effect on the earth is of an inductive nature, and is usually slight; this is the case with what is called *sheet* lightning, in which the clouds are vividly illuminated, but there is no line of light visible. In the other class the surface of the earth forms the second condenser plate, the air and all bodies between the clouds and the earth are "polarized," and assume a condition analogous to that produced in the neighbourhood of an electric machine at work. Discharge at last occurs in one or more lines in which the resistance happens to be least,

when the tension has risen to a degree greater than the resistance of the circuit can sustain. Very slight circumstances determine the direction of this discharge: an animal standing on the ground, a tree, the presence of extra moisture, or a metallic vein, or a range of piping in the ground may suffice. This is very evident in the case of ships at sea: they will not only draw a flash of lightning, but there is good reason to believe that they frequently cause a change in the direction of the wind itself by the electrical conditions they set up. It is a common circumstance for a squall-cloud to arise and work half round a vessel, and at last come towards it and take it aback more or less suddenly. If the path of the cloud be traced out it will be found to be of the nature of a parabola; the original motion being gradually diminished, and its direction diverted to the vessel. I have frequently seen this occur; and on one occasion a very heavy squall-cloud rose on the weather bow of a ship I was in; it crossed our course and went away to leeward, we running up nearer and nearer to its path: the cloud then stopped, rapidly returned toward us, against the wind we had, and as it reached above us, a violent change of wind occurred, the cloud threw out its charge, struck the fore and main top-gallant masts, and killed two men.

It will be easily conceived that a large vessel, with its three masts the only salient points arising from the earth's surface in the neighbourhood, must produce a great effect upon the electrical conditions around it, and that this may frequently be the cause of the sudden changes of wind experienced. To this same order belong a variety of natural phenomena, such as what sailors call St. Elmo's Fire, when the points of masts and yards are tipped with lambent flames, which resemble the common brush discharge of our machines. A third variety, called Ball Lightning, is very uncommon, and its electrical nature is not at present explainable; if, indeed, it is directly electric in its nature at all. In this a large ball of fire is seen to roll along the earth, doing great mischief on its path, and apparently having some connection with, or relation to, the revolving winds called tornadoes or whirlwinds, models of which may frequently be observed in our streets when the dust is not properly laid by watering, and of which the waterspout is another variety.

384. In the true thunder-storm the cloud consists of a series of layers or zones oppositely electrified, with a similarly arranged, but opposite series on the earth beneath, the air between completing an electric circuit. Such a circuit is often extended over many miles, so that when a discharge occurs at one extremity a corresponding one in the reverse direction (sometimes called the back stroke) occurs at the other extremity, perhaps twenty miles away. The clouds themselves may be only 100 feet away, or two or three

miles. Flashes of such length have indeed been measured by the angle occupied by the line of light and the period between the flash and the sound of the thunder, which together furnish the means of calculating the length of the visible flash. Several attempts have also been made to measure the time occupied by a discharge. Moving objects, when photographed by its light, appear as distinct as if stationary, but by means of revolving mirrors it has been ascertained that the actual duration of a flash is something less than $\frac{1}{500}$th of a second; its apparent duration is an effect of our own eyes, due to what is called persistence of vision, owing to which we cannot lose an impression once produced in much less than a sixth of a second, on which principle are based so many optical toys.

385. It is frequently stated that the bodies of those killed by lightning are marked by impressions of neighbouring objects. It is hard to say what amount of truth there is in this, and how much natural exaggeration; credit is most often given to a neighbouring tree as the image copied, and it would seem not unlikely that such marks are caused by an action like that of the brush discharge, causing a series of straggling lines, which the imagination of excited observers converts into a tree. It is of more moment to those who are alarmed at the flashes of lightning to understand that when a flash is seen all danger from it is passed; a person struck never sees the flash, and it would appear that this death is the most instantaneous and painless which can be conceived.

386. The foregoing considerations as to the nature of the discharge will enable us to see what are the true principles of conductors to avoid its effects. They are not intended to attract or convey a *discharge from* the clouds; their object is to supersede the condition of polarization and tension in the *space to be protected.* They do this in a twofold manner:

(1) They practically raise the earth's surface to such a curved height as corresponds to the electric relations of the conductor and the air; not in an exact invariable form, as some suppose the protected area to assume; but still, roughly in a cone from the apex of the conductor, and of a radius perhaps equal to the height of the point, but this applies only to the rod itself; when buildings are in the included cone no law can be given, as the conductivity is affected by their materials and contents. Whatever the space protected may be, within it the conductor lowers or nullifies the condition of tension, transferring it to the space outside the cone, &c. (2) They react also upon the exterior space in the direction of a reversed cone, by the discharging properties of points when forming part of a polarized area, as explained, § 50, p. 43. When a point connected to "earth," or the rubber of the machine is approached towards the prime conductor, the latter cannot be charged, but a brush discharge occurs and a current is produced instead. The lightning

conductor acts in the same manner; as soon as the charged cloud approaches, and would begin to set up an "inductive circuit" under tension in the air to the earth beneath it, a current begins to flow quietly in the conductor, the tension above it is rapidly lowered, and may not be able to accumulate sufficiently for a violent discharge, i. e. a lightning flash, at all; but if it does, the discharge will occur through the space between the cloud and the outer area of the conductor's cone; and the conductor takes it up in the form of a momentary increase of current. In considering these principles it must be remembered that lightning is not a mere thread of flame, or confined to the visible line; a large space all round the line takes part in the discharge, and gives up the force previously accumulated in it as tension.

387. These principles settle conclusively all questions as to the construction of lightning conductors. Their object should be to connect to earth every portion of a building; and as this is actually possible only with metal buildings, they should connect every salient point and as much of the surface as possible, so as to extend around the building the area of low tension, or artificial "earth" surface opposed to the cloud. Chimneys require especial attention, because they are tubes lined with conducting material, containing warmer air, and if with fires, then extending a comparatively good conducting column of warm air towards the cloud and so inviting a discharge; hence it is that lightning almost always enters a house by the chimneys. All doors and windows causing currents of air should be closed during a thunder-storm.

388. The prime essential is a good connection to water; water and gas mains provide the best if the conductor is well secured to them; next to them is the metal shaft of a good pump, in a well constantly supplied by springs; then ponds or ditches. What is required is a large metal surface terminating the conductor, and in contact with a stratum of moist earth, so that a hole sunk into wet gravel, into which the conductor is led, and surrounded with a quantity of coke to increase its surfaces of contact, will answer, but dry clay, or rock, is not safe. This connection should, if possible, surround the building by means of rods from its various corners, either led to different earths or else continued by a rod round the house to one earth connection. Every piece of metalwork about the building should be utilized, such as ridge-caps, guttering, and water pipes. They cannot be trusted as conductors because of the joints in them, which offer great resistance, and therefore prevent reduction of tension, but they will help to form a protecting network around the building, especially if strips of copper are soldered across each joint. For the same reason a connection should be led from the bottom of the down pipes from the gutters to the nearest suitable earth, though a very good but vari-

able earth connection is set up from these by the water itself during heavy rain. The lower parts of bell-wires may also be advantageously connected to an earth, such as the nearest gas or water pipes, as several accidents have occurred from their having either received a direct charge through the walls, or having a violent current induced in them.

389. The terminals should be attached to all high or salient points, most particularly chimney-stacks; if these are wide, and contain several chimneys, it is safer to have two points, though usually one is sufficient; but the kitchen chimney, or any one commonly used, and therefore lined with soot, and containing warm air, should be specially attended to. The points may be made of rods of 1-inch iron drawn out to a point, rising 2 or 3 feet above the building; they are better also for galvanizing. There is no advantage in any of the fancy points, patented or otherwise. The conductor depends upon the size and height of the building. A factory chimney or church steeple should have a copper conductor of at least ½-inch section, either as a rod or as a wire-rope, well protected against injury; for smaller buildings, iron-rod may be used instead of copper. In ordinary cases galvanized iron wire of about a ¼-inch diameter (such as is used for telegraphic purposes)* will answer perfectly, if led separately from various salient points, and carried down the different sides of the house and connected as above described, to the guttering, &c., but for a single conductor at least ½-inch rod should be used. Solid rod is best, as it exposes least surface to rust, for it is the mass or weight of metal which conducts, *not its surface*, as some suppose; but every joint must be carefully made and soldered, to secure metallic continuity and low resistance.

390. It will be seen that conductors should never be insulated from the building, but, ont he contrary, as much of the surface as possible should be connected to the conductor. Electrometers, &c., are often surrounded with a cage of wire connected to the earth or to the negative pole of the active source of electricity, in order to prevent them from being affected by external electric disturbances. That is exactly what we require to do with our buildings; an iron house well connected to earth would not only be perfectly safe, but its inmates would scarcely feel any of the effects usually produced on the nervous system by "thundery" weather, except so far as these are due to heat. The object aimed at in a lightning conductor should be to approach that condition as nearly as possible; to obtain an enclosed area within a conducting envelop provided with points and connected to earth.

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* Recommended by Mr. Preece, whose experience in this matter is very considerable.

CHAPTER XII.

ELECTRO-MAGNETISM.

391. Throughout these pages the transmission of electric current has been regarded mainly as consisting of a breaking up and reformation of the molecules which form the polarized chain or circuit, this being the action which undoubtedly does occur in electrolysis where the action can be best examined. But no single conception will convey the whole of any scientific truth, and it has been indicated, especially in § 260, p. 220, that transmission may be effected by other means (such as *rotation* of the molecules) dependent upon the same causes, such as the polar attractions of the molecules, which in electrolysis produce actual disruption.

392. It is indeed very difficult to conceive that the same action occurs in solid conductors such as wires, as takes place in liquids, because no change whatever appears to be produced in the wires. We might indeed conceive that in solids the freed semi-molecules at each end of the wires unite with similar ones to reconstitute the metals unchanged in physical property and form. But an experiment will prove that in solids this action does not occur: we cannot conclusively test it in simple substances such as metals, but some metallic sulphides which are true binary compounds, and which would, if fused, be electrolytes and undergo the process of breaking up, are conductors also when solid. Now I have interposed a piece of such a sulphide between two plates of silver (which has a strong affinity for sulphur), and passed current for some time : there was no formation of silver sulphide, and therefore it is clear no such action occurred in the solid sulphide as would have occurred had it been in the liquid state.

393. Rotation of Molecules.—A rotation of molecules involving a reversal of their polar arrangement will, however, fulfil all the conditions required, and in examining the relations between magnets and electric currents there will be found good reason to believe that such a rotation does actually occur in solid conductors, and that the direction of what we call the galvanic current, that is to say, its magnetic and chemical relations, depends upon whether this rotation takes place on an axis inclined to the right hand or to

the left of the polarized chain itself. It is intended to go into this subject only so far as is necessary to understand the action and construction of magneto-electric machines and induction coils. Even this will require a re-examination of some subjects dealt with in Chapter III. on Magnetism, but which belong more properly to the present subject. In fact, this chapter is an addition to the work as originally planned, and has been written since the other part of the book was printed.

394. Whenever a magnetic body and an electric conductor are brought near to each other, or moved in each other's neighbourhood, they react upon each other if either one of them is under the influence of either force, magnetism or electricity. A magnet will produce a current in the conductor if either is moved under certain conditions; electricity in motion as current, confers magnetism on a magnetic substance. The reason of this reaction is that the two are really different manifestations of the same force, and are due to different actions of molecules in a state of polarization; the electric action is that exerted in the line of polarization; magnetism is the action at right angles to the line of polarization; it is exerted in every direction at right angles, and, as a consequence, magnetism has in itself no directive power, and, strictly speaking, *no polarity.* The apparent polarity, like the directive power of magnets, is not the property of any single magnetic substance or object, but is the consequence of the mutual reaction of two or more such objects. It is the possession of magnetism by the earth, which therefore acts as one such body, that confers upon magnets their apparent directive power.

395. The source of all the mutual actions of magnets and currents is to be found in that property of the molecules of matter which we call *induction,* a power of acting externally upon other molecules. Within the electric circuit itself this power sets up the condition of "polarization," or arrangement of molecules in an order of regular sequence (+ –) (+ –) (+ –); but besides this action *in the circuit,* a similar action is exerted *around the circuit,* which tends to place surrounding molecules in a parallel polar order. But while the first action is consistent with a transmission of energy along the circuit, and is thus of a dynamic character, the second is static, and changes only when there is a change of conditions. Thus, if we pass a current into a submarine cable, two conditions of polarization are set up; one in the line of the wire; the second in the surrounding matter, in the form of an *inductive* circuit from each successive point of the wire through the water to the other pole of the generator. This latter absorption of energy is called "charge," and the current cannot be set up, that is, the *conductive* circuit cannot be completed, till from point to point of

the wire the inductive circuit is completely charged; this is the cause of what is called *retardation*, and hence the rate at which signals can be transmitted through a cable depends upon the nature of the inductive circuit it forms, or its "inductive capacity." But once this charge is given, the inductive circuit retains it, and absorbs no more energy from the current (except what is lost by *leakage*); current can be sustained upon the ordinary laws so long as no change is made. But when the current stops, the energy of charge flows out of the cable as a current, and no current can be sent through the cable, in the opposite direction to the first, until this first charge is passed off and a new one of the opposite order is set up.

396. Now magnetism is of the same order as charge; it is a static condition of the molecules, set up by energy absorbed from an electric current (or other source); while this condition is being assumed the process acts as a resistance and a retardation; but once it is set up, it is static, requires no more energy, and the energy will be retained, or given up as an electric current, according to the nature of the body in which it is produced.

397. To apprehend the consequences we must regard the electric circuit as a simple chain of polar molecules and individualize the molecules, which I shall do by drawing them as ellipses, of which the dark part will represent the + end, or the direction in which we may conceive the supposed electric current to be travelling; the white, or − end, being that connected to the positive pole of the battery. Fig. 71 is a section of such a chain, looked at from the positive pole, that is to say, the − end facing the observer, with the line of electric polarization passing through the centre.

Fig. 71.

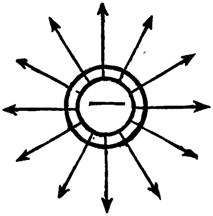
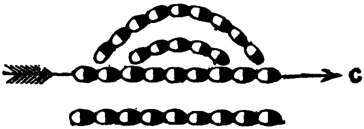


Fig. 72.



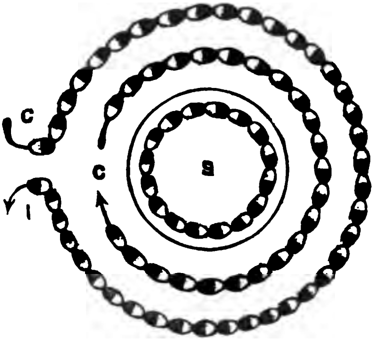
The molecule exerts that action which we call magnetism, at right angles to the polar line in every direction, as represented by the arrows; but this action has no *directive* power, no *attractive* power; these depend upon external conditions.

398. But the molecule, or, more correctly, the polarized chain, has the power of ranging all surrounding molecules in similar order, as shown in Fig. 72. The upper lines are intended to convey

the idea of the inductive circuit set up as "charge." The lower parallel line represents the magnetic conditions to be further developed.

399. If we conceive the polarized chain C, of Fig. 72, to be formed into a circle, as in Fig. 73, we obtain the two effects in different ways. Let S be a section of a bar of steel; its molecules arrange themselves in the form of closed chains, and as steel possesses the power of retaining this condition, it becomes a magnet, the forces exerted at right angles to the direction of polarization, all combining and acting in the line of the bar, as shown in the upper bar S N, Fig. 76, and also in Figs. 74 and 75. The difference between the two extreme faces of this bar is that, looked at from the exterior, the lines of polarization turn to the right in S and to the left in N, as seen in the two polar faces shown in Fig. 76. There is no difference of property, no inherent directive tendency in these ends; but in England we call the face S the south pole of the magnet because it ranges itself in the earth's magnetic field, facing to the south pole of the earth. In France they call it the N., or Boreal pole, because it has the same magnetic character as the north pole of the earth.

FIG. 73.



400. But action takes place externally, as well as within the ring. If *i c* is regarded as a ring of wire, its molecules, of necessity, swing into the polar order, and in doing so constitute a galvanic circuit, which will complete itself as usual; in consequence, a momentary current is generated or induced in this "secondary" wire as soon as current passes in C: but only one wave of action is produced, no current continues to flow in *i c*. As soon as the primary current ceases, all the molecules resume their normal

position, and in the act of doing so a current is again set up in *i c*, but in the opposite direction to the first. If S is iron, instead of steel, it loses its magnetism, and the energy it had stored up is employed in increasing the energy of the current in *i c*, and also in producing an *extra* current in C itself, continued after the battery is cut off. These all react upon each other in such manner that these currents are not, as usually considered, single currents, but consist of several pulsations of maximum and minimum force analogous to the swings of a pendulum raised and let fall. The current in the secondary wire, at making contact in C, is in the reverse direction to that of C itself: at breaking circuit the induced current is in the same direction as that of C. As these currents are each the result of single and equal swings of the molecules, their "quantity" is the same, for quantity is simply a function of the molecular actions. But the E M F of the breaking current is much the greatest. The reason is obvious: in the first, energy is being taken up in *i c* and in S; in the last, that energy concentrates chiefly in *i c*.

401. If S, instead of being a bar of iron or a bundle of iron wires, is made of an insulated iron wire wound up in a helix similar to the other wires, it will still act as a magnet, though less forcibly, owing to the breaks in the longitudinal or magnetic lines, but the *extra* current will then be formed within itself and the wire will give off sparks.

402. The *direction* of these and all the other actions among currents and magnets, *induced* by motion (which includes the setting up or cessation of a current, these being equivalent to a motion of approach or withdrawal), is governed by a general law first formulated by Lenz. *The direction of the current set up by any motion will be such as will resist that motion, and vice versâ.* Now currents having the *same* direction, that is, parallel, *attract* each other; therefore a current in the *opposite* direction, which *repels*, is set up. The order of the lines of circular polarization in magnets (Fig. 73) acts in the same manner as would the corresponding current, which is represented by C. We may see in this some analogy to the action of two wheels in contact; when one is rotated in one direction it sets up in the other a motion in the opposite direction. Therefore the induced current at "make" is in the opposite direction in the wires to that of the primary, as then the two currents *repel* each other: at "break," the induced current is in the same direction as the original or primary current, as this resists the demagnetization or withdrawal of the magnetic energy, or magnet.

On examination of Figs. 74 and 75, it will be seen that there is a cause which may determine the direction of rotation of the molecules of wires, &c. If the turn of wire C (Fig. 73) is a true circle, there would seem to be no reason why the molecules should turn to one side rather than the other in assuming the polar order. But in a helix the direction of the wire is compound: besides the circular turns there is the equivalent of a straight length from end to end of the core, and the action of the turns is exerted at a small angle to the core, which of necessity gives the impulse to the molecules in the direction of that angle.

403. In consequence of these various relations, a wire wound spirally round a bar of iron magnetizes it in a direction determined by the direction in which the wire is wound. On the other hand, if the bar be magnetized by any external means, as by bringing another magnet in contact or neighbourhood, a current will be induced in the wire, and the direction will depend upon that of the magnetism set up, and also upon the direction in which the wire is wound. Helices are called *dextrorsal* or *right-handed*, when, looking at them from the end at which the current enters, or at which the coiling of the wire commences, the wire turns from left to right over the core as the hands of a watch. Fig. 74 is a right-handed helix, and, as it shows, such helices give South polarity to the end at which the current enters. In *sinistrorsal* or *left-handed* helices the wire, under like conditions, turns from right to left over the core, as in Fig. 75, and gives North polarity to the end at which the current enters. A right-handed helix becomes left-handed if looked at from the other end; therefore when the wire of a right-handed helix returns over itself, by continuing to wind in the same direction, the upper layer becomes a left-handed helix; but as at the same time the direction of the current reverses as regards the core, the mutual reaction of wire and core is the same in all parts.

FIG. 74.

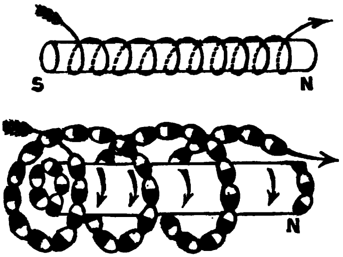
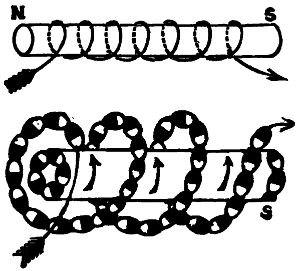


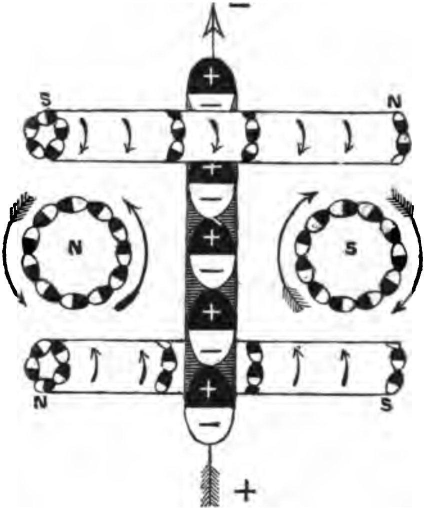
FIG. 75.



The figures speak for themselves, and show the mutual molecular relations as well as those of electric and magnetic polarity, the effects produced, and the reason of them.

404. Fig. 76 carries these relations a stage farther. The electric conductor is shown as a line of molecules upon the arrow which marks the direction of the current; four magnetic bars surround it, above, below, and on each side, and the molecular arrangement of these shows at once why they place themselves as they do (assuming the earth's influence to be neutralized): the ends of the two side magnets correspond with those in Figs. 74 and 75, as the other two magnets do with the bars in those figures. It will be seen that the magnets arrange themselves as though the lines of polarization were actually currents all made parallel with the current itself,* and just as the corresponding helices would if currents were traversing them.

FIG. 76.



405. We have now to consider how the magnets react. A magnet is not merely a bar of metal; it includes in its energy the surrounding matter in which are completed the lines of magnetic force, and which constitutes what is called a *magnetic field*, which field is an integral part of the magnet. When a magnetic substance is near, it draws these lines towards itself, and by entering them becomes magnetized, but in ordinary conditions we may regard the lines of force as enclosing an elliptic space round the magnet, and treat Fig. 71 as a section of a magnet and its field. But Fig. 77 gives

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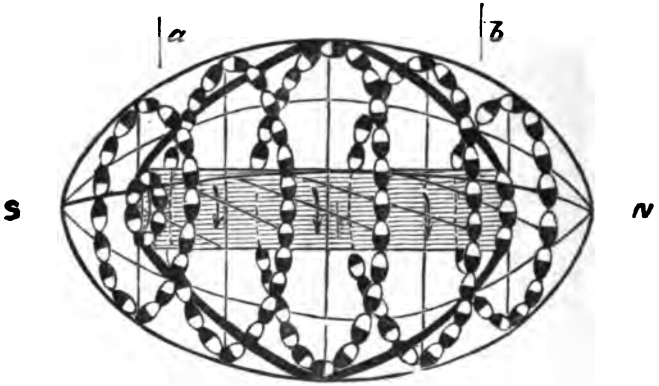
* See Ampere's 'Theory,' p. 73.

the idea more completely. From it we can see that the lines of force of the field, which enclose the ellipse, may be looked at from a twofold aspect. They are commonly treated as set up by the *poles* of the magnet, and as completing the circuits of *magnetic* polarity; for many purposes it is desirable to so regard them, and this view is presented by the elliptic lines. But we may with equal truth consider that the polarized condition is set up by the circular polarization of the magnet forming the *vertical* circles, and so regard the elliptic or magnetic lines as being set up indirectly by the action at right angles of these circles. We shall thus understand why the *inductive* power of a magnet is so much greater at its middle, while its *attractive* power is so much greater at its ends. The attraction is a function of the general law that parallel currents attract each other; there is, in fact, in all spiral conductors a tendency to close up, because of this attraction between all the partial currents. Now, if we conceive another figure like Fig. 77, brought near it endwise, it is evident that to make the lines of polarization alike, the north end of one must be presented to the south end of the other, and that then not only do the circles of the bars agree, while all the circles of each magnet, internal and external, attract each other, but the projecting lines of force of each magnet become incorporated with those of the other, and the result is a new elliptic field. Hence, naturally, long magnets have the greatest attractive power, for they may be regarded as such combinations of smaller ones, combining their magnetic force, just as the union of galvanic batteries in series combines their electro-

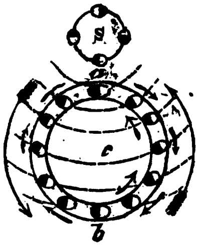
FIG. 77.



motive forces. But as to induction, it is evident that the external circles are affected by those of the bar more powerfully at the middle than those at the ends can be by the whole length of the magnet, as this influence obeys the law of the squares of the distance; therefore, speaking roughly for illustration sake, if we consider the inductive action of each circle of the bar to be equal, and call it 10, a circle at the middle will have a force of 20 exerted upon it by the two end circles, but a circle at the one end will be acted upon by the middle, 10, and the other end, whose distance is doubled, will give only $10 \div 2^2$ or 2·5, a total of 12·5 upon an end circle against 20 on the middle circle. This is the reason why a coil of wire with a current passing through it will draw a magnet into its middle, or *vice versâ*, the arrangement according with that shown in Figs. 74 and 75, while a magnet with the opposite arrangement placed within a coil will be forced out.

406. If we examine the actions which will take place upon the molecules of a conductor revolving in any position among the lines of force of a magnetic field, as shown in Fig. 77, p. 326, we shall see that different effects may be anticipated according to the direction of the motion; we shall be aided in examining the effects if we regard Fig. 73, p. 322, as a vertical cross section of Fig. 77. If the axis of motion be in the central line, N S, and the motion takes place in the circles of Fig. 73, the molecules suffer no change of position as regards either their relation to S or to their arrangement in the moving wire; hence no effect can result. If the axis be lowered, so that the motion takes place below the central line, it will be seen that each molecule, in order to retain its relation to the magnetic field, must in each revolution rotate once on its axis in relation to its accompanying molecules in the wire itself. This is evident in Fig. 78, which represents a ring of wire rotating on the centre *c*, in the direction of the outer arrows, below the magnet S, of which the dotted circles are the lines of induction. It is obvious that the molecules forming the wire, in order to keep their relation to these circles, turn on their axes in the direction of the small arrows, and in doing so set up a current in the wire. This *explanation* is, of course, hypothetical, but it is *a fact* that the motion of the conductor under these conditions does produce some action within the wire which results in an electric impulse. This figure brings before the eye also the different external polar actions of such a ring, for it will be noted that the molecules on any diameter have the opposite extremities turned

FIG. 78.



towards any wire which may be imagined in contact, and therefore would induce opposite polar conditions in such wires; so that if the wires were connected a current would be produced in them: the molecules at *a* and *b* on the vertical line, it is obvious, would in this case exert the greatest inductive power.

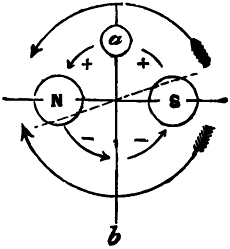
407. If a plate of metal is revolved under or above a magnetic pole, or between the poles of a horseshoe magnet, but below the middle line of the poles, as new sets of molecules are brought into action, sets of opposing currents are set up in the conductor, and can be collected by means of a pair of springs, one pressing on the centre of rotation at *c*, in Fig. 78, and the other on the circumference at the points where the currents meet, which in the latter case is on the radius between the poles of the magnet, or at *a*, Fig. 78. These currents develop a great resistance to motion, and the conductor itself becomes heated. This was the first form in which Faraday demonstrated the setting up of an electric current by motion of a conductor within a magnetic field.

If a bar of iron be surrounded with a helix of wire a current of induction is set up when the iron is magnetized, and another in the opposite direction when it loses the magnetism; or the same effects are produced if a magnetized steel bar is inserted into and withdrawn from a helix. If a helix is wound upon the arms of a horseshoe permanent magnet, currents are in like manner set up whenever the armature is applied to or removed from the magnet; when a perfectly fitting armature of sufficient size is applied to a magnet the capacity of its metal for magnetism absorbs all the energy the magnet can exert into its own mass; the magnet then becomes inert as far as external influences are concerned; hence the application of the armature is tantamount to destroying the magnetism, so far as external relations are concerned, as stated p. 76.

408. All the practical forms of magneto-electric machines are based upon some of these principles. The earliest and simplest form consists of an armature of horseshoe shape revolved across the poles of a horseshoe magnet. The wire is so wound that if the horseshoe was straightened out, it would form one continuous helix, and in order to do this, it is usually wound on two similar reels, the inner ends taken to the commutator, and the outer ends connected together. When such an armature revolves over a magnet, the two ends are in opposite conditions, and therefore whatever action tends to develop a + condition at one end of the wire tends to develop a − condition at the other end, and therefore both coincide in producing a current through the wire, as explained § 401. We may, therefore, examine the action upon one end of the wire in a complete revolution. Let *a*, Fig. 79, be the end of one helix

resting on the neutral line *a b* of the magnetic poles N S, and the line of motion be from *a* to N. North magnetism is being gained; and let us assume that the relation of the helix is such that this renders the end +. As soon as *a* passes N its north magnetism is being lost, hence the wire reverses its polarity; as soon as *a* passes the neutral line it begins to gain south magnetism, and (as gaining north makes it +) this gives it − polarity, which on crossing S, and when the south magnetism is being lost, again becomes +. We have thus four electric impulses which, being however in couples, and not alternating, resolve themselves, as may be seen, into two electric conditions. By means of a commutator on the line N S, therefore, a current can be obtained in one direction, though not continuous, but composed of the action of four distinct impulses, analogous to the varying electromotive forces set up by discharge of a condenser. A great part of the energy is lost also at the commutator, where a spark is produced if there is an actual break of circuit; for this reason it is usual to make the change of circuit in a diagonal line, instead of in the line of the axis, as shown Fig. 80, in order that the spring may not jump from one to the other, but press on both together for an instant. By this means the spark is avoided, but the energy it represents is none the less lost, as it passes by the short circuit thus formed.

FIG. 79.



409. It must be understood that the point of change is not *practically* upon the line N S, but upon a line in advance of it, as shown by the dotted line, Fig. 79. The reason is that the various molecular changes, and especially the absorption of magnetism, require time; hence the line of actual break will take a position dependent upon the quality of the iron of the armature and upon the rate of rotation; it is even possible to conceive a rate of rotation such that no effect is produced at all, and in practice the motion cannot be advantageously increased beyond a certain rate, at which the maximum effect is produced.

In some instruments, notably in Ladd's dynamo-electric machine, the break of the commutator is placed on the line *a b* instead of on that of N S, the reason for which I am not able to give unless it lies in the foregoing remark, the rotation in this machine being very rapid. There are also some complications in the action similar to those examined, § 417, which may also render this mode of connection advantageous.

410. SIEMENS' ARMATURE.—All the early forms of magneto-

electric machines consisted of a rotating horseshoe armature, such as just described; this plan, however, involves great loss of power by friction and by churning the air. Nowadays this form is employed only in the common machines made for medical purposes. The form of armature shown in Fig. 80 was devised by Siemens to avoid these evils. A is a solid soft iron armature of a section resembling that of an H girder, with the faces turned down to arcs of a circle. The wire is wound longitudinally, as shown in section in the middle of Fig. 81. The coil may be covered with a sheathing of wood so as to form a solid smooth cylinder, in which case grooves are turned in the face to contain fastenings to hold the wood in its place. On the ends of the armature, brass plates are securely screwed to form the axis of rotation, and carrying at one end *p*, the driving pulley, and at the other end the commutator, *c*. This consists of a cylinder of ebonite fixed upon the axis, upon which are secured the two halves of a gun-metal cylinder, cut diagonally, as shown; the ends of the wire of the armature are led through the end pieces and secured to these. Frequently one of the connecting pieces is fixed to the axis, and one end of the wire to the armature, instead of isolating both. Springs like *s*, fitted with a turned pad of steel or other metal, press upon the cylinder and take up the current; they are usually made in one piece and cause great pressure and wear; it is better to cut them down as shown, in order to give more elasticity. This form of armature is used in many machines, one form, for medical use and small experiments, consists of several steel magnets of a circular form, with a circular opening cut through to form the poles, in which the armature rotates. The currents from these, or any armatures, obey the same laws as those of induction coils, to be considered hereafter. The quantity, or current, depends on the size of wire used; and the electromotive force or tension set up, upon the number of turns.

FIG. 80.

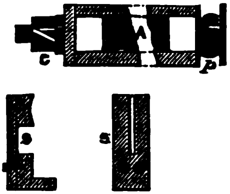
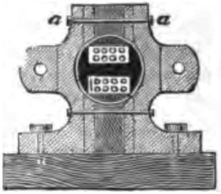


FIG. 81.



411. WILDE'S MACHINE.—In this there is a new idea developed which has proved very fruitful. Instead of using the current produced by the armature of a magneto-electric machine in

direct work, Mr. Wilde passed it into a large electro-magnet itself fitted up in a similar manner, and obtained from this a greatly increased current, which might be used, or might again be transmitted to a still larger electro-magnet. In fact, the apparatus is based upon the conception that "*a current or a magnet indefinitely weak can be made to induce a current or a magnet indefinitely strong*," by using it as an agency to convert mechanical exertion or energy into electrical current. There have been many forms of instrument since devised, but all depend upon this fundamental idea.

Fig 81 will explain the principle of construction: *a*, *a*, are two blocks of cast iron of such length as may be required in each case; they are separated by blocks of wood or other non-magnetic substance, and bolted together by brass or copper fastenings; a cylindrical opening is bored through, in which the armature, Fig. 80, rotates. At the proper intervals there are lugs, as shown, to which are to be bolted the actual magnets, either steel or soft iron, as required: *a*, *a*, form, in fact, the poles of a compound magnet, and, if preferred, may be made in separate pieces for each magnet; all surfaces in contact with the true magnet should be carefully faced so as to secure a large surface contact. Cast iron is better than wrought iron for these polar pieces, because, like steel, it assumes the magnetic condition, and this enables it to play an important part in the electro-magnets: these are charged only by the current from the first armature, and, as seen, § 408, this is intermittent. But it is desirable to keep the magnetism constant, particularly as each change in it is accompanied by a reacting current in the wire, and consequent waste of energy; the cast-iron polar pieces, by their resistance to demagnetization, maintain the magnetic condition in the iron connected to them: they thus serve the purpose of the flywheel in engines, as they convert the intermittent magnetizing impulses of the armature into a steady magnetism in the iron.

The arrangement of the machine itself is simply a matter of mechanical convenience, for the two parts are quite distinct. It is made, however, with the large electro-magnet on a stand, and the small permanent magnet fixed above it, each with a driving strap from its armature to a pulley on an engine or driving shaft.

412. **Ladd's Machine.**—Shortly after the publication of Wilde's machine, the idea occurred to several electricians, among others Mr. Siemens and Sir Chas. Wheatstone, that the permanent magnet might be dispensed with, and replaced by an electro-magnet; the first idea was to charge this by a momentary current from a battery, and then to send the current from the armature into the coils of the electro-magnet itself. But it was at once found that the original idea of Wilde might be carried much farther. Any iron once magnetized retains a feeble trace of "residuary magnetism,"

and the earth itself induces a slight magnetism in iron properly arranged; it was found that this slight magnetism was sufficient to start with, that it continually grew, as the current it developed returned into the wires, until the saturated condition was attained. Then the current might either be diverted for a short time to an external circuit in which momentary currents only are required, and such instruments are applied to telegraphic purposes: in other cases the current of the armature could be divided into two or more "derived circuits" with resistances arranged so that the requisite proportion should be sent into the electro-magnet and the rest be utilized.

Mr. Ladd devised a convenient form of applying these later ideas. His instrument takes several forms, but Fig. 81 will enable its principles to be understood. In one form there are two such end pieces as Fig. 81 shows, connected by electro-magnets formed of boiler plate folded up into a flattened cylinder; one armature is used to generate a current which passes into the coils of the electro-magnet; the other supplies the current which is to be utilized for external purposes.

In another form, one of these ends is replaced by a cast-iron arch connecting the two electro-magnets into a single horseshoe. The armature itself is, however, made compound; instead of A, Fig. 80, being a single piece, it is cut into two, separated by a brass plate in the middle, by which they are secured at right angles to each other, forming two distinct armatures acting alternately, and employed in place of the separate armatures of the other form; of course a commutator is also fitted to the other end. If preferred, two wires might be wound upon one armature and used for these two purposes.

413. *The Gramme Machine.*—In this, the latest development of electro-magnetism, a new principle has been again developed, but the instrument itself is as yet so little known that its principles of action have been very imperfectly studied. The main practical distinction between this and all other forms of magneto-electric machines is this, that it furnishes *a uniform and constant current in one direction*, while all others give intermittent and alternating currents, which have to be arranged by the commutator. The reason of this is easily seen; in all the other machines the wire in which the current is set up is constantly altering its position in the magnetic field, and is as a whole subjected to a growing and diminishing action in two opposite directions, hence the electromotive force set up is *of the nature of a succession of waves* alternately rising above and sinking below the zero line; and the current resembles the stream set up by strokes of a pump. In the Gramme machine, although *each part* of the wire is constantly

changing its relation to the acting magnetic field, *yet the wire, as a whole*, never changes its relation to, or position in the field; hence the inductive conditions set up are constant; the electromotive force set up is *of the nature of a constant fall of water*, and the current is a steady stream. To understand how this result is arrived at, it is necessary to examine the apparatus and the conditions from several distinct points of view.

414. GRAMME'S ARMATURE.—The essential distinction of the machine lies in its armature; this term is scarcely correct indeed, but I use it for the express purpose of keeping up a connection with the ideas which the other machines set up. This armature is no longer a bar, or a horseshoe, but a complete ring of soft iron. The wire is no longer a length of wire having two ends forming a constant circuit; it is a continuous and endless piece of wire wound over every part of the ring. The current does not flow through this circuit in its entirety, first one way and then the other, but two opposing currents flow in those parts of the wire which occupy, at each instant, a fixed relation to the inducing magnet, or rather no current flows at all (considering, that is, the circuit itself), but two equal and opposite electromotive forces are set up, which unite in producing current if an external conductor is provided. When the conditions of this armature are perfectly understood, it will be seen that all the other parts of the machine, and its electric actions, are identical with all the other forms. In it, as in them, either permanent or electro-magnets can be used, and these latter can be excited by the machine itself, exactly as in Ladd's machine.

FIG. 82.

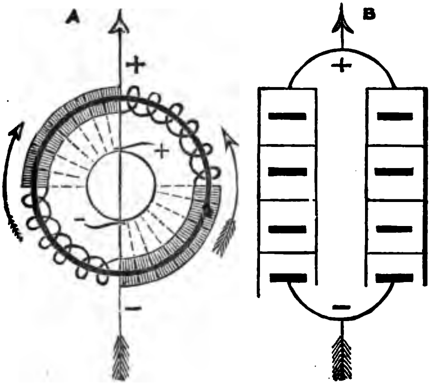


Fig. 82 explains the construction. The wire is wound continuously in the same direction upon the iron and its two ends joined together; but though this wire is endless, it is necessary that there should be a constant connection with it at the points where it is cut by the vertical line + − ; *looking at the armature as a whole*, and as regards its relation to the magnetic field, the electromotive forces set up are shown by the arrows which, it will be seen, represent the same conditions as a pair of equal batteries connected with their forces opposed, as regards themselves, but in multiple arc as regards an external circuit. In such an external circuit, therefore, they combine to set up a current; if no external circuit is provided, no current is generated. But the *different parts of the armature*, as it revolves, are constantly changing their positions in the field, and therefore a temporary or shifting connection to the wire has to be made as each of its turns crosses the vertical line. If the wire were a single layer, this could be accomplished by exposing its exterior surface and arranging a spring to touch at each point. Practically, this same condition is attained by dividing the wire into a great number of equal sections, and attaching a conductor to each section in such way as to act as would the single turns of the wire itself. This is effected by bringing these conducting branches out to an insulated cylinder faced with as many insulated contact pieces as there are sections of wire to be connected; this is shown by the dotted lines in the figure which represent the connecting wires; springs pressing on the contact pieces make, practically, a constant connection with the two halves of the circuit on the vertical line. In the machine itself these springs are replaced by brushes of wire thick enough to press on, at least, two contact pieces. The object is to prevent any actual break of contact in order to avoid the production of sparks at the commutator; there is also less mechanical resistance than a strongly pressing spring would cause.

415. We have only to conceive this armature inserted in the place of the Siemens' armature in Fig. 81, p. 330, in order to follow out its relations to the magnetic field, and to trace out the points in which the Gramme machine differs from the others. The real distinction has not as yet been defined in any of the attempted explanations of the machine. In all other forms the armature, *as a whole*, reverses its relation to the magnetic field, and *assumes two distinct conditions at different times.* In the Gramme, *the different parts* of the armature assume these conditions *successively*, and thus set up a rotation of the molecules of the wire as in other machines; but, *as a whole, the two distinct conditions are assumed at the same time* in the two halves of the armature on each side of the vertical line in Fig. 82.

In the revolution of an ordinary armature, the electromotive force set up in the wire, as a whole, varies with its distance from the inducing magnet, and, in consequence, the current produced is variable. Now, the various sections of the wire of the Gramme occupy all these different positions at once; the consequent variable electromotive forces are, therefore, generated in them as in the ordinary armatures; but these sections being connected together in series, they act exactly as do a series of cells of different electromotive forces, and the resulting electromotive force in each of the sides of the ring is constant, and is the sum of all those of the sections it contains. The action of the two halves of the ring A (Fig. 82) corresponds, therefore, in all respects with that of the two equal batteries, shown in B as coupled in multiple arc. In both there are equal opposed forces resulting in static equilibrium, and in both there is combined action on an external circuit.

The wires may be stout or fine, according to the current required, or each section may consist of a flat ribbon wound in a tight spiral. The resistance obeys the law of derived circuits, and is, therefore, one quarter of that of the length of wire employed.

416. **Theory of the Gramme.**—The foregoing is an accurate description of what really occurs, but the manner in which the effect is produced is by no means clearly understood, nor do the several very elaborate explanations published at all clear the matter up. The result really appears to be the residuary or ultimate effect of several distinct actions, some co-operating and some opposing; part of the effect is due to the magnetizing and demagnetizing of the successive parts of the rotating ring, each of which actions reacts upon the part of the wire surrounding it; part, again, depends upon the effect produced upon the wire itself as it traverses the magnetic field.

If we place a short helix upon an iron bar which is magnetized, and slide it along the bar, a current is produced in the wire, variable in different parts of the bar, because of the different inductive effects. If the bar were closed into a ring, magnetized but having no poles because it is a closed and self-contained magnetic circuit, a constant current would be set up in the moving helix. If two such bars were joined into a ring with similar poles opposed, the currents would be variable and would change in direction on crossing the polar junctions. Fig. 83 shows us that the ring of the Gramme forms such a pair with the similar poles on the line *n s*, we may therefore regard each section of the wire as the helix traversing the compound ring or stationary magnetic circuit; but beside the effect due to this, as the metal of the ring moves, its molecules undergo the usual changes which react inductively on those of the wire, just as though each section were a separate helix with a bar undergoing the process of magnetizing and demagnetizing.

These are the principles developed by Count du Moncel and M. Gaugain, so far as they can be extracted from the mathematical expressions they employ. Fig. 83 is modified from one given in the 'Mechanic's Magazine,' April 27, 1872, and therefore I give with it the explanation there given, also somewhat modified. Let us regard the turn of wire to the left of 5. As the ring rotates in the direction of the arrows, the face of the iron on the line 5 becomes more strongly N as it approaches the inducing magnet N; when it passes the point 6 it becomes neutral or nearly so, and this change induces a current in the wire. After it passes the point 1 the face becomes S with an intensity diminishing as far as the point 2, and then increasing till it passes 3. Each of these changes sets up its equivalent current as shown by the arrows in the ring. The conditions are therefore analogous to those shown in Fig. 79, p. 329, and each successive section of the wire develops the E M F appropriate to its own relation to the inducing magnets, and to the magnetic action taking place in the ring within it.

FIG. 83.

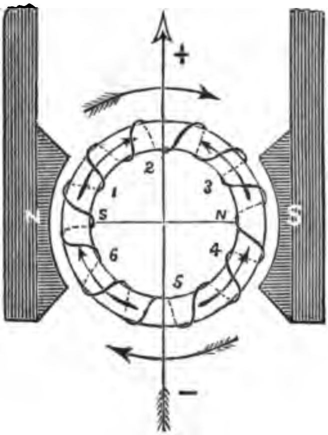
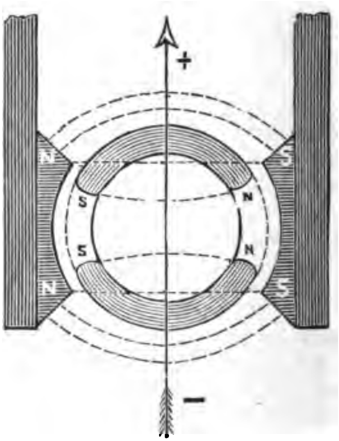


FIG. 84.



417. Fig. 84 is an endeavour of my own to trace out the sum of the actions. In it we regard the magnetic field set up and neglect the rotation of the iron ring altogether. It is evident that the wide poles, N S, of the inducing magnet must set up *two distinct magnetic fields* in the same direction, as shown in the dotted lines, corresponding to the ellipse of Fig. 77, p. 326. On this view the ring consists of two curved bar magnets, with their fields, and with opposed poles having a neutral space between. We may

then examine the action in the wire by considering a single section as a short helix moving over the bars. Starting from S in the upper bar, it is exposed to a growing inductive action, till it reaches the middle line, where all the inductive actions of the principal magnets, and of the included bar, are at a maximum, and tend to make the wire led out to the commutator positive, or +. When this helix traverses the lower magnet, the same conditions recur, but tending to make the same wire negative, or −. Therefore the points intersected by the vertical line + − are those of high and opposite inductive influence, tending, whenever a conductor is interposed, to set up a current externally, and dividing internally by the two branches; and it would seem probable that this condition has an important influence on the result actually produced.

But we may also regard the space between the dotted lines of Fig. 84 as a single magnetic field, the conditions of which will then be represented by the circles of Fig. 77, p. 326; by the aid of this figure we can trace out the molecular conditions which will be set up in a small helix traversing a circular path in the field, which will be nearly represented by the thick lines in Fig. 77 if we conceive the ring of molecules forming the end of the bar to be strung upon this thick line. In the vertical position at the top it will be seen that the lower half of the ring would be exposed to a force tending to reverse the position of its molecules, but that the forces which tend to maintain the position are the greatest: by the time the ring had reached the lower vertical position its molecules would have had to make a semi-rotation in order to retain their relation to the field: on passing the line S N, the ring being then horizontal (instead of vertical, as drawn in the figure), the molecules of the wire would be arranged across the wire instead of lengthways; in this position also, each side of the wire being exposed to similar conditions, there is a conflict of forces, and the actual position assumed would be that due to the excess of the various forces acting in one direction over those acting in the other direction. It is therefore evident that no single way of looking at the action of the armature of the Gramme can possibly explain the effects produced.

418. **Construction.**—In the machine which was employed to supply the light at the Houses of Parliament, and which was also exhibited in action at the works of Messrs. Wheildon and Cooke, the side-pieces or poles N S, in Figs. 84, 85, which correspond to the blocks *a a*, Fig. 81, p. 331, consisted of two massive rectangular blocks with the inner faces turned true; to each of these there were secured three circular electro-magnets above and below, the other ends of these were secured in massive iron plates, thus

forming the framework of the machine. Fig. 85 is a vertical section, and Fig. 86 one through the middle horizontally. It will be seen that there are three separate rings, one of which supplies

FIG. 85.

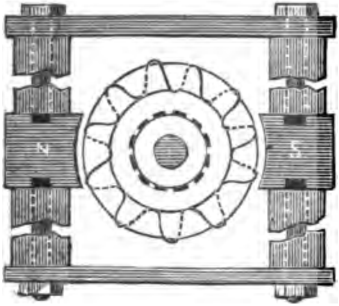
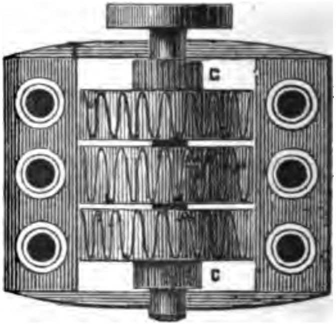


FIG. 86.



the current for the electro-magnet; the other two are connected as one to the commutator for the external work; *c c* are the commutators, to which connections are made from an insulated frame attached to N and S at each end.

In this machine the resistances were—

The main electro-magnets	Ohms 3·6
The ring for exciting the magnets	„ ·57
The two rings for external work	„ ·37

Its electromotive force increased with the rate of revolution, its best working power being about 320 revolutions per minute.

At the Houses of Parliament it was worked by a steam-engine in the basement, the current being conveyed to the lamp 479 feet distant, by means of copper rods $\frac{7}{16}$ inch diameter, and about 1700 feet long, according to Mr. Douglass' report. Making 389 revolutions per minute, it absorbed 2·66 horse-power, and gave a light equal to 3066 standard sperm candles.

419. RATIO OF CONVERSION OF ENERGY.—Dynamo-electric machines unquestionably furnish the electric current at a cost lower than that of galvanic batteries; but, as yet, no one knows what the actual relative cost is. The makers always express their work by saying that they will heat so many inches of platinum or iron rod of such a size; this kind of measure is quite indeterminable, as may be seen p. 142, § 193, especially as the conductivity is very variable: others say that they are equal to so many Bunsen's cells, and that they take about so much horse-power to drive. No one seems

to have yet perceived that the essential requirement is to ascertain exactly, on one hand, the energy expended, such as the indicated horse-power employed in driving, and, on the other, the actual current developed in some definite unit (such as the British Association veber or my chemic) in a known resistance, and under different conditions of resistance; from these data the actual energy utilized could be calculated.

However, I have done this for one of Ladd's machines in a series of experiments carried out in conjunction with Mr. Desmond G. Fitzgerald.

The machine employed was the form made for 1 man-power, which Mr. Ladd says will heat to whiteness 18 inches of platinum wire ·01 inch or 10 *mils* diameter. Its resistances were—

The inducing magnet	Ohm	·815
Magnetizing armature	„	·112
Working circuit „	„	·129

Each turn of the handles gives 15½ turns to the armature. The work done when a fair rate of motion was attained was proportional to rate of revolution, 41 turns of the handle giving 3 cubic inches of mixed gases in a large surface voltameter, whether turned at 80 or 160 turns a minute; about 78 turns a minute were as much as a strong man could maintain for any considerable time, and at that rate it takes 12·2 minutes to produce one equivalent of the gases, the mechanical equivalent of which (p. 212) is 6841 foot-pounds. The energy expended per man-power is considered to be ⅙ of a horse-power, then 33000 ÷ 6 = 5500, and this multiplied by 12·2 gives 67,100 foot-pounds, or about one-tenth of the mechanical energy is utilized as current.

420. As this process is not exact, we arranged a mechanical apparatus in which all the details could be exactly tested. This consisted of a rope driving a barrel and multiplying wheels, by which the machine itself could in turn be driven at any suitable velocity, by means of a heavy weight falling through a distance of 32 feet in 2½ minutes, so that the residual energy of the weight might be disregarded, and the extra weight required at each stage of experiment represented actually the work then under examination. 1. Weight was used enough to work the driving apparatus alone. 2. Weight was added to drive the machine, with the armature exchanged for a piece of wood, to test the simple friction, which absorbed nearly half the total energy required to work. 3. Extra weight was used as necessary to drive at different rates, with varying resistances interposed, and the current produced was carefully measured under the various conditions.

The result agreed with the first experiment; the work in foot-pounds by the formula $C^2 \times R$ came closely to one-tenth of the amount of the weight multiplied by 32, that is, the foot-pounds mechanical energy expended. This is about the same ratio as the steam-engine really utilizes of the energy of coal, and if this is anything more than a special case, it would appear that we might reckon the cost of electricity thus obtained as ten times the cost of steam-power, which it will be seen in § 423 is ·0011 per equivolt, bringing that of electricity to ·0112, which figure may be compared with those in Table VI., p. 120.

421. It has been stated that Marcus, of Vienna, makes dynamo-electric machines which worked by 1 man-power are equivalent to a Bunsen cell consuming 500 grains of zinc per hour. If these figures are true, the result is very much better than that just shown. 500 grains of zinc is about 15 equivalents, and taking the data of Table VI. represents (15 × 1·6) 24 equivolts produced. A horse-power 33000 × 60 ÷ 4673 = 423·7 equivolts, that is to say, a man-power expended is only 70·6 equivolts, which gives us one-third instead of one-tenth utilized.

422. *Work of the Gramme.*—I was unable to measure either work expended or utilized in the Gramme machine with any exactness; some experiments have been published, however, in which the work in silver depositing done by a Wilde machine and one of Gramme's was compared. It is said that 1 horse-power was used, but it is uncertain whether each machine was so arranged as to utilize the power to equal advantage. The average of a series of experiments with an anode of 57·62 square feet shows a deposit with the Gramme of 26·89 ounces of silver per hour, and with an anode of 28·81 square feet 20·55 ounces, and with the Wilde 16·53.

It is stated that the Gramme gave an electromotive force equal to 2 Bunsens and a quantity of 32. Now if the E M F is correct and is taken as 3·2, then 20·55 ounces being a current of 913·3 chemics, or 160·8 vebers per second, brings the resistance of the circuit to ·0199 ohm, which is a very unlikely-looking result. But working on these data gives us the mechanical equivalent of the currrent of the Gramme as 293·3 equivolts against 423·7 used (1 horse-power), being 69 per cent. utilized. The Wilde, on the same data, gives 189 equivolts, or 45 per cent. utilized. Neither of these results appears trustworthy.

423. **Energy of Fuel.**—In studying the present subject it is necessary to understand clearly these relations of energy, and this is easy by the aid of the equivolt unit. According to the table, p. 212, the energy of carbon is 9624 foot-pounds, or 2·0594 equivolts. But in most treatises on heat, it is usual to value the work of fuel, &c., in terms of units of heat, generally that amount of

heat which will raise 1 pound of water 1° Fahr. in temperature: such values can be converted into the equivolt by dividing by line 28, Table XVII., p. 217, or by multiplying by its reciprocal ·166 or Log. $\bar{1}$·2180099. On this system, according to Favre and Silbermann, the value of carbon per lb. is 12,906 units, and of hydrogen 62,535. According to the Government experiments on coal the average of English qualities may be taken as—

Carbon, per lb. .. .. ·812 × 12906 = 10480
Hydrogen (available), per lb. ·041 × 62535 = 2564

Equivolts, per lb. .. .. 2154·9 = 13044

Taking the price of coal as 20*s*. per ton as an average figure from which actual cost is readily derived under any circumstances, we get the cost of coal per lb. ·1071 of a penny, and per equivolt ·0000497. We must next consider the proportion of this actually utilized in ordinary steam-engines. This will depend upon their consumption per "indicated horse-power," and this varies from 2½ lb. per hour in the best engines to 5 and 6 in common ones.* A horse-power is 33,000 foot-pounds per minute, or 1,980,000 per hour = 423·7 equivolts; if, then, we take 4 lb. of coal per hour as an average consumption, this brings the practical mechanical equivalent of the pound of coal to 105·9 equivolts, and the practical cost of steam-power per equivolt ·00112 of a penny. On these data the average steam-engine utilizes only one-twentieth of the potential energy of its fuel.

A man's power is usually taken as ⅙ that of a horse-power, or 70·6 equivolts, and at 8*d*. per hour, costs per equivolt ·1133 of a penny.

424. ELECTRO-MAGNETIC ENGINES.—Many attempts have been made to drive machinery by means of electro-magnetism, but all are failures. A sketch of the fundamental principles at issue may serve to prevent readers from wasting their time uselessly, or to guide them in the only possible useful direction. The considerations examined, § 426, will show that electro-magnetism cannot possibly compete with the steam-engine unless a very cheap source of current can be obtained. But for some small kinds of work, where only momentary or occasional action is necessary, and the

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* The indicated horse-power is usually employed as the measure of work and merit of an engine, but it is not really so, as it does not allow for the friction of the engine itself. The correct value can be ascertained only by some kind of dynamometer which measures the actual mechanical energy exerted at the driving pulley of the engine per indicated horse-power developed in the cylinder, as this latter measures the proportion of energy of the fuel transformed into pressure on the piston by the agency of the boiler and cylinder.

mere cost is of slight moment compared with convenience, electromagnetism may be advantageously used to do mechanical work, as indeed it does whenever employed to ring a bell or give a signal in telegraphy.

Engines must be of one of two classes. (1) *Rotatory*, in which a series of armatures are mounted on a wheel acted on by several electro-magnets arranged at different distances from an armature, and each is in turn thrown into circuit to act on an approaching armature; this is effected by having more armatures than magnets: the armatures may be iron simply, or they may be electro-magnets, in which case repulsion may be employed as well as attraction. (2) *Reciprocating*, like the beam steam-engines. In these an armature on a lever is attracted and released by an electro-magnet, or the lever may be double and so made into a beam with a magnet on each arm. The greatest effect has been produced by using hollow helices, the lower half containing iron, with a plunger of iron to be attracted into the helix. In either form the commutator, which is actuated by the moving axis, must be carefully arranged to throw the current into the proper circuit only while it can do effective work.

It is important to give the armature as little motion as possible, because the effect of distance is to decrease the attraction in a ratio at least equal to the square of the distance, § 429, while power can be gained mechanically by leverage at the equal ratio of the distance or length: therefore the driving point should be at a greater distance from the axis than the armature is.

425. A new construction of electro-magnets has lately been published by Mr. J. S. Camacho. I tried the same principle some time ago, and it greatly increases the power to be obtained. Instead of a solid or single core of iron surrounded by a helix, the construction is compound: an ordinary small cylinder and helix is surrounded externally by another cylinder of iron and a helix, and so on, thus placing a large part of the inducing currents in the interior of the magnet itself, and securing a greater inductive action on the iron. The following figures are given as to a machine which has been tested at Habana: The interior diameters of the iron tubes are 48, 76, 106, and 127 mms., the inner one made of iron 13 mms. thick, the other 7 mms. The wire is copper of 3 square mms. sectional area (about No. 16) in two layers, or 180 turns on the three inner tubes, and seven layers with 630 turns on the outer cylinder, all connected in one length. The length of the arms is 212 mms., the weight 35 kilos., and that of the wire 19 kilos., with a length of 800 metres.

With 7 bichromate of potash cells, it is said to exert an attractive power of 552 kilos. at 2 mms. distance, "while one of ordinary construction of equal exterior diameter only supports 11 kilos., 50 times less." This must be taken *quantum valeat.*

426. *Cost of Working.*—The exact method of estimating energy explained in the preceding sections, and especially the use of the equivolt unit, which renders all the facts comparable, will show why all electro-magnetic engines fail. The whole question resolves itself into one issue: *What is the cost of an equivolt of energy?* The cost, by even a common steam-engine, is ·00112 of a penny. Table VI., p. 120, shows its cost when obtained from the various forms of galvanic battery, and these figures must be doubled at least to ascertain the cost, when transformed into mechanical work by aid of magnetism, that is to say, electro-magnetic power must cost more than 100 times as much as steam-power.

The figures given in the books are even too favourable to the electro-magnet. Thus Joule calculates that under the most favourable circumstances an electro-magnetic engine would consume 75 lb. of zinc in a Daniell's battery to maintain 1 horse-power for 24 hours.

Now Table V., p. 119, shows 201 equivalents per lb. of zinc, and the Daniell's force is 1·079, therefore 75 × 201 × 1·079 = 16266 equivolts; a horse-power for 24 hours is 10,168 equivolts, and twice that amount at least is required; but taking these figures and setting the cost of the battery as only 4 pence per lb. of zinc, we have 25 shillings, while 96 lbs. of coal, costing, at 20 shillings per ton, 10·29 pence, would in a common steam-engine do the same work.

427. The following table is a supplement to Table VI., and shows at one view the various facts. It relates only to materials consumed.

COST OF MECHANICAL AND ELECTRICAL ENERGY PER EQUIVOLT = 4673 FT.-LBS.

Detail in §§.	Apparatus.	Cost in Pence.
	Mechanical—	
423	Coal, potential	·0000497
423	Steam-engine	·00112
423	Man's power	·1133
426	Electro-magnetic	·1122
	Electric (see Table VI., p. 120)—	
420	Magnets utilizing one-tenth	·0112
421	" " one-third	·0038

428. ELECTRO-MAGNETIC LAWS.—The following statements as to the laws which govern the construction and actions of electro-magnets are collected from various sources: they relate to the

three elements which constitute an electro-magnet: (1) the iron core; (2) the helical wire; (3) the current which is passed:

1. The power to deflect a magnetic needle is proportional to the square root of the diameter of the core; the lifting power, to the simple diameter. (Dub.)

2. The attractive power increases as the mass of the iron, and this is proportional to the square of the diameter of the iron cylinder, the lengths being equal. (Pfaff.)

3. The form of the iron influences its power. Cylinders carry greater weights than rectangular bars, and a hollow cylinder from which a portion has been cut away so as to form a long horseshoe magnet when viewed in the direction of its axis, but a very short one if taken as to its height, is capable of receiving a very great suspensive force: a slight curvature of the polar surface adds to its power. (Pfaff.)

4. The free magnetism at the poles of a horseshoe magnet is proportional to the square root of the length. At any given transverse section it is proportional to the difference between the square root of half the length and the square root of the distance of the given section from the nearest end. (Dub.)

5. The magnet's suspensive power increases as the number of turns of the wire, or the total effect is equal to the sum of each taken singly. (Pfaff.)

6. The free magnetism of an electro-magnet is directly proportional to the number of turns of the helix. (Jacobi.)

7. Its attraction is proportional to the square of the number of convolutions. (Dub.)

8. The attraction between two electro-magnets is proportional to the sum of the product of the current strength and number of convolutions of both helixes. (Dub.)

9. The material and thickness of the wire are (when the current is equal) without influence upon the magnetism. (Lenz.)

10. The free magnetism of the end faces of an electro-magnet is proportional to the current strength. (Dub.)

11. The attraction between electro-magnets is proportional to the square of the strength of the current.

Noad gives the following generalizing formula:

12. Let M = the magnetic force of the electro-magnet.
n = the number of convolutions.
d = diameter of the core.
C = the current passing.
c = a constant (not stated).
then $M = c\,n\,C\sqrt{d}$.

The several resistances of course have a bearing on the relations, as under like conditions the current depends on the resistance, and the resistance and number of turns are related to the size of the wire.

When the resistance of the coils of the electro-magnet is equal to the resistance of the rest of the circuit, the magnetizing force is at a maximum.

The magnetizing powers of coils (of the same metal) with the same surface of battery plates arranged so as to give the maximum current, are as the square roots of the weights of the wire used. (Menzzer.)

Formulæ are frequently given as to the relation of the resistance of the wire to that of the battery, but these are very delusive: it is the current passed and number of turns of wire which are to be considered, the resistances are of importance only as they influence these.

429. **Attractions of Magnets.**—The supposed laws of attraction of magnets are delusive: the attractions of magnets can follow no definitive law of mere distance, for the relation depends upon the magnetic field. Let us conceive a flexible bar of iron covered with a helix and bent up into horseshoes of different form, that is, with greater or less openings between the poles. Each arrangement would set up a different magnetic field, as will readily be seen by means of the principles of § 405, p. 325. The closer the poles are brought together, the greater weight would an armature in contact be able to carry, because the force would be more intense in the armature; but the difference in powers would not be vast, providing the armature itself was properly adapted to engross the inductive power of the magnet (to do which it must be at least as large in section as the magnet itself). But the wider apart the poles, at the greater distance would a given attractive energy be exerted, because the field would occupy a larger ellipse: therefore doubling the distance in this case would reduce the attractive power much less than it would in a magnet with its poles close together, and therefore with a small and intense field.

430. **Electro-magnetic Coils.**—These are an application of the principles studied §§ 399–405. They consist of distinct parts, the function of which should be understood. 1. The iron core. 2. The primary wire which conveys current from the battery. 3. The break which interrupts the current. 4. The secondary wire in which the induced current is set up. 5. The insulation. 6. The condenser.

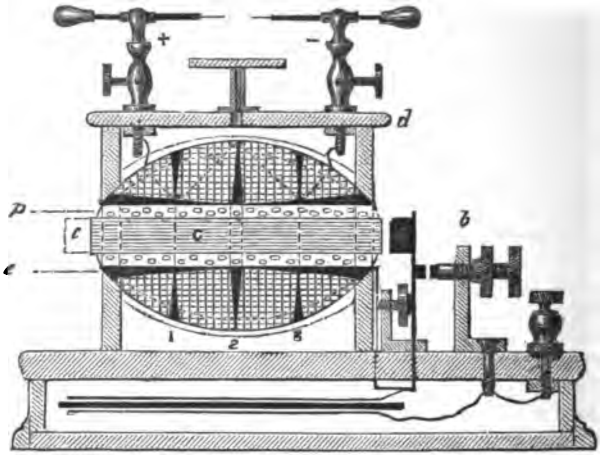
Between all these parts there is a due proportion, and Fig. 87 is drawn to a scale intended to exhibit that proportionate relation for the best construction: it represents a coil 1 foot long in the core, and 1⅛ inch diameter.

The ellipse shows the most advantageous form in which the wires can be arranged, to occupy the most effective portion of the space marked in thick lines from the points *a b*, in Fig. 77, p. 326. The inner dotted line is the space adapted for a smaller quantity of wire. There are many other modes of construction which may be occasionally glanced at, but the following explanation is intended to assist in the actual making of a coil to the best advantage.

431. *The Core.*—This acts purely as an electro-magnet, and should be made of the purest and softest iron, so that it may magnetize and demagnetize as rapidly and completely as possible. It must not be capable of setting up an induced current within

itself, therefore its own metal must not form a circuit which would act as does the brass covering tube described § 443. It is composed, therefore, of wires of the best quality of No. 18 to 22 gauge, cut in lengths somewhat in excess of the intended core, so as to project at both ends, as shown in dotted lines at one end *c*: they should be made up into a truly round form, which is best done by aid of a metal cylinder of proper size, split from end to end, and bound with wire or cord while the wires are packed: it should then be slid off gradually while a strong wire is wound tightly from end to end of the bundle: this should then be placed in a charcoal fire, made red hot for some time, and allowed to cool as the fire goes out—not by removal. The binding wire should be gradually unwound, and replaced by a strong tape covered by strips of stout paper glued or pasted on to form a cylinder, which, when dry, should be warmed and dipped in melted paraffin, which should soak thoroughly in.

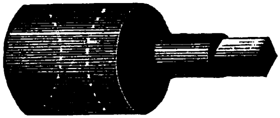
Fig. 87.



Another plan is to use a mandrel of hard wood slightly tapering; form the paper cylinder on this, make the coil complete as follows, and insert the core afterwards; this latter plan is the easiest, but the core is not so perfect, and space is apt to be lost between the core and the primary, which is disadvantageous, unless it is desired to have a removable core for purposes of experiment; then it and the primary may be made to slide in the tube on which the secondary is wound.

Fig. 88 represents a cap of metal to be fitted on to each end of the core or to the mandrel, to work in a slot in an upright frame so that a handle can be slipped on either end to wind up the coils of wire. This could be done in a lathe, but is far better done by hand in a frame for the purpose.

FIG. 88.



When the coil is completed, the caps (which may be best secured by shellac cement) are removed, the end of the core at *b* is to be cut off and filed to a perfectly smooth face: the end *c* may advantageously be left on, as shown, projecting beyond the calculated length of the core, as it and the armature at the other end will both add to the inductive actions.

432. *The Primary.*—This may be cotton covered, but is better silk covered, because the laws (§ 428, 5–7) show that the magnetism induced in the core depends upon the current and the *number* of turns of wire, and this number will be greater, the less room the insulation takes up; for this reason, and as there is little tendency to escape, the wire should not be coated with paraffin, &c.: it should be of the softest quality and the highest conductivity possible. The proper size is of the utmost importance: it must be selected with an eye to the battery power intended to be used so as to develop the greatest current. It is wise to err on the side of using wires *too small* rather than the reverse, because that error partly compensates itself by the greater number of turns, and may be corrected in working by using an extra cell or two. No. 14 would suit a coil a foot long to work with low battery power; for smaller coils, No. 18 and even 20. It should be in one length, in case of any accident occurring at a join, and also to avoid irregularity of form which is apt to be caused by a joint. The question as to the advantage of two or three layers is of the same order as that of size; it is a matter of resistance, current, and space occupied: the balance is in favour of two layers. This also brings the two ends to one extremity; if three are preferred, the end of the wire must be brought out and carried back under the stand in mounting. Place the core in the frame, tie the wire firmly to it with a sufficient length for connection, and wind up as firmly and closely as possible, beginning at the left hand, and turning the handle upwards to form a right-handed helix. When the layer is completed, fill up the furrow between the wire with a soft cotton cord, or stout knitting cotton, which has been well baked and soaked in paraffin, then bind over firmly with a strip of dry silk or silk binding (such as the drapers call Prussian or flannel binding), to

prevent any accidental contact by chafe of the wires. Now continue winding on the second layer, and secure it in the same manner. It will be wise now to test the resistance of the wire, which should be slightly greater than before winding: if it is less, there is contact somewhere, which must be remedied by unwinding. The core and primary should now be warmed and well soaked with melted paraffin.

433. I may here suggest that an electro-magnet built up as described, § 425, would probably constitute a very admirable basis for a coil; for this purpose each of the iron cylinders should have an open slit from end to end, for the purpose of preventing current induction within it.

434. *Insulating Tube.*—The core and primary are now to be enclosed in a tube, as shown by *e*, Fig. 87, which requires to be thicker at the ends than at the middle, as drawn. An ebonite tube is usually recommended, but it is very costly and difficult to fit exactly to the primary without waste of space. Such a tube can advantageously be built out of the *thinnest sheet ebonite.* Measure the proper size with a piece of paper cut to fit tight; cut out a piece of the ebonite, which is best done with a sharp point, or a tenon-saw drawn over the surface; hold it before a fire till it softens, and bend it over the coil, binding it down with a tape till cold; then secure the joint with shellac. In a large coil a second cylinder should be used, breaking joint at the opposite side, and the surface of the first should be painted with shellac varnish, so as to just stick when the next is applied. Three discs of the thin ebonite are to be cut, with central holes to suit the position, as shown, and slipped upon the cylinder, which is then thickened up on the ends by shorter cylinders, as shown. When dry these may be turned down to a regular curve, if desired, or the discs being set in position, a strip of paraffined paper may be wound on to the desired thickness, as directed in the winding of the secondary. In discs 1 and 3 there are to be holes through which a length of the secondary wire is passed, as shown. In small coils a single disc will suffice; in larger ones others are to be added so as to leave no space wider than 2 to 3 inches, but so as to keep an even number of spaces. The discs are to be thickened alternately at the middle and edges, so that the thin part is where the wire passes from one compartment to the next, that is to say, where the difference of tension is least between the neighbouring portions of wire, this obeying the law of tensions, and corresponding to the actual length of wire intervening between such neighbouring parts. There are two ways of thickening discs: another disc of sheet ebonite may be cut of the proper size and rasped away at one edge, and cemented with shellac on each side of the principal disc; or discs of paraffined paper may be cut and added at intervals as

the wire is wound on, which is readily done by cutting a slit in each so as to slip it on, breaking joint of course at each. The first plan is preferable when the thickness is in the centre.

The two end pieces may be made of ebonite, but well-baked mahogany saturated with paraffin will answer. The inner faces may have a recess cut in them to contain a circle of thick sheet ebonite where in contact with the wires, and if desired, a casing of thin ornamental wood can be used to cover the real ends. In most coils these ends are circular, with a flat face at the lower edge; but in Fig. 87 they are rectangular, in order to carry the terminals and discharger. Whichever plan is preferred, they are now to be fixed firmly upon the insulating tube so as to enclose within them part of the primary, as shown, forming a complete reel. The insulating tube should be carried to the end of the core (instead of being cut off to the ellipse, as shown in the figure), so that the ends may be fixed securely upon it.

435. *The secondary wire* is to be laid on with its turns parallel to those of the primary, and there should be as many turns got into the space as consists with the other essential conditions. The size of wire depends upon the object aimed at. A full bushy spark depends on *quantity*, and this again depends entirely on the size of the wire. Length of spark depends on *tension*, and this upon the number of turns. These conditions are explained § 439, and the size of wire will range between Nos. 35 and 40. The coil is to be arranged in the winding stand as before, with the *b* end to the left, or in the reverse position to that of Fig. 87. Fix pieces of wood or cork in all the spaces, except the end 3 *b*, to support the discs, and then wind the wire on, turning the handle as before, away from the body upwards to form a right-handed helix of the wire, which is to be wound on with the precautions as to insulation described § 436, filling up to the elliptic outline, and leaving the end out, for connection to the terminal. Next fill up the space 1–2 in the same way. Now *turn the reel end for end* in the frame, bringing it as it is in Fig. 87, and fill up the other two spaces, turning the handle the same as before; then as the wire commences at the other end of the space and its position is reversed, the spires will all be in the same direction and be a continuous helix, when the two ends at partition 2 are soldered together.

The object of this construction is to concentrate the tensions at the two ends of the coil where perfect insulation is most easily effected, and to secure the most perfect insulation where it is most required: it is for this purpose that the tube is thickened at the ends to resist any tendency to strike to the primary.

In the common, because easy, construction with the secondary wound backwards and forwards from end to end, as in Fig. 89, it is obvious that a great length of wire intervenes between the proximate ends of two separate layers, and there is in consequence great risk of a spark breaking through the insulation, which in such case ought to be thicker there than at the ends at which the layer turns back on itself.

436. *Insulation of Secondary.*—The wire itself should be silk covered; it should be well baked, and laid on while quite dry. It is better for being paraffined, if this is so done as not to enlarge the size (§ 442). Between each layer an insulating film is spread, which is usually made of several thicknesses of guttapercha tissue, but it is doubtful whether good paper paraffined, such as is used for the condenser, is not better. The best mode of applying either is to cut it in long slips half an inch wide, fix the end over the end of wire, and wind spirally, so that the strip overlaps half its width. On reaching the end or partition, great care is to be taken that the space is perfectly filled, which is easily done by forcing in a little softened paraffin; the strip should then be folded back on itself close to the wall of the space, again wound spirally back half-way up the space and returned to the end, where it can be left to support the next layer of wire: by this means there are only two thicknesses interposed where little insulation is needed, and four where it is most required. In long spaces or undivided coils, the strip should be returned two-thirds of the length, and again for one-third, so as to have six thicknesses at the dangerous ends. If paraffined paper is used, the final process will make all secure, but if guttapercha is employed, it will be an improvement to paint round the ends at each layer with shellac cement. Some paint the whole wire thus when laid, but this renders it next to impossible ever to remove the wire if desired. Guttapercha dissolved in benzole or in oil may be used instead of shellac.

When the coil is completed, similar external insulation should be employed, filling up the outer dotted line, Fig. 87. This should be of an air-proof nature, such as paraffined paper or solid guttapercha, otherwise the guttapercha sheet is apt to be destroyed by the action of the air. If paraffin insulation is used, the coil should be slowly warmed for some hours, and then saturated with melted paraffin before applying this external covering.

The continuity of the wire should be carefully watched throughout, as described § 442, or at least tested as each layer is completed, lest any break should occur unnoticed. It is also a great advantage to test the growing inductive action as the coil progresses, which is one reason also for building it on the core itself. At the earlier stages this may be tested by a suitable galvanometer, connecting up a single Daniell cell to the primary, with a hand contact key interposed, and observing the deflection produced on making and breaking contact: of course, the whole length of wire to be used for the coil must be connected to the secondary from the first, or at least it must be made up to one uniform resistance, so as to observe the increasing electromotive force generated. When the coil has so far progressed as to give sparks, a discharger may be used, and the break key should have the condenser attached. The increasing spark can be thus watched, and any accidental failure of insulation at once detected before it is covered up. The construction of a large coil is a matter of so much labour that these precautions are of great consequence.

437. *The Break.*—The construction of this is simple, but involves important principles. Its objects are, (1) to close the battery circuit fully, with as little resistance as possible. This requires a good contact surface at the platinum points and a strong pressure of the spring. (2) To maintain the contact till the core is fully magnetized. This requires the resistance of the spring to be just sufficient, so as not to allow the armature to be moved until the full magnetism is approached: for this reason it is desirable to place the point, as shown, at some distance down the spring, which then assumes a curve before actually destroying contact. To assist this the spring may be of taper form, thinning away towards the upper end. (3) The iron armature must be of the best soft iron and as massive as the core itself; it in fact acts as a prolongation of the core, and assists the inductive actions.

The construction is simple, as shown *b*, Fig. 87. The spring is secured to a brass bracket, which carries also a set screw, by which the distance between armature and core and the resistance of the spring are adjusted. A similar but higher bracket carries a screw pointed with platinum, and provided with a loose set nut to prevent its shifting with the vibrations. The platinum should be soldered in position, but care must be taken that no solder runs over it. A hole should be drilled in the point of the screw, and tinned by means of a pointed wire, and the platinum wire entered firmly in. The piece on the spring may be a piece of thick wire, in which case a hole should be drilled in the spring, in which a reduced end of the platinum may be entered, riveted up, and touched with solder on the back. A piece of stout sheet platinum may be used, in which case the spot it is to occupy should be tinned, the platinum placed, and the iron carefully applied round the edges. Platinum requires to be moistened with flux to enable solder to take readily.

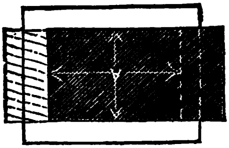
For some experimental purposes a break worked by hand or mechanism is useful, and consists of a spring pressing on a ratchet-wheel revolved at a fixed rate. This may be interposed between the coil and battery, the ordinary break being screwed tightly up.

438. *The Condenser* is made as described § 61, p. 53. The area

of foil it should contain depends upon the degree of battery power to be used, increasing with this: excess in size is, however, no evil. The two faces are connected, as shown, Fig. 87, to the spring and the screw of the contact breaker. The function of the condenser is not thoroughly understood, but it absorbs the extra current of the primary and reduces the spark at break of contact, which would otherwise destroy the platinum. The effect is to facilitate the demagnetizing of the core, and consequently to increase the electromotive force of the secondary current at break of circuit.

Fig. 89 shows a convenient mode of constructing the condenser. A shows the foil projecting half an inch beyond one end of the paper, and with an inch margin left round three sides. The sheets of foil may be each fixed by warming and by pressure on a sheet of paper. The first sheet being laid with the tinned side beneath, another is laid with the foil above, and in the position shown by the dotted line, so that the two papers are between the foils: two uncoated sheets are then laid, and then the process continued as required. The rectangular space included by the two arrows is the effective area of the foil.

FIG. 89.



Experiments have been published lately by M. L. Boltzmann on the inductive capacity of insulating materials, differing from those given on p. 53, as follows:

Vulcanite	3·15
Paraffin	2·32
Sulphur	3·84
Resin	2·55

In the cheaper coils, condensers are made of sheets of ordinary paper without any preparation interposed between the foils.

The best mode of ascertaining the size of the condenser adapted to a coil is to arrange it as described for making, and lead temporary wires to it from the coil, allowing this to work at intervals, increasing the battery power gradually to the utmost likely to be used, and adding sheet after sheet of the foil as it is observed to produce beneficial effects.

439. THE LAWS OF COILS.—The effects of a coil depend upon the size of the secondary wire, and its length as mentioned, § 435. *Size* or *thickness* of spark depends on the *thickness* of the wire: *length* of spark depends on *length* of wire; the laws are in fact the same as those of batteries and of the heating of wires, § 193, p. 144.

We may regard each turn of wire as an electromotor analogous to a cell of a battery, or to a thermo-electric couple. At each section of the coil equal *electromotive force* is developed in each turn, whether close to the core or at the outside of the coil; but the distinction must be remembered between the electromotive force developed *in* the turn, and the effect produced externally *by* the turn: this will correspond to the actions of a large or small cell of equal force, and, therefore, the inner turns exert more energy than the outer, because their own internal resistance is less in the ratio of the lengths.

So also the electromotive force developed *in* the turn is independent of the nature of the metal of the wire, but as the *effect* produced depends on the resistances as well as the electromotive force, wire of high conductivity ought to be used; it will also develop less internal heat. It is, however, a question whether iron may not form an exception to this, because being magnetic it would absorb energy itself, and thus increase the electromotive force it could develop, but it is doubtful whether this would counterbalance the disadvantage of the extra resistance. It is very doubtful whether any definite law of construction has been as yet arrived at, generally applicable. The principles here laid down apply fairly to coils up to 18 inches in length, and it is usually considered that with adequate battery power a spark ought to be produced at the rate of an inch per mile of secondary, but the coils which have been made of unusually large size have not given anything like a proportionate effect. A few instances of noticeable coils are given in § 441, which show this.

Coils may be united as cells are, and upon the same laws, and it would seem that more effect would be obtained from the same materials and currents applied in four coils of a foot long than in one single coil, but coils to be so coupled would require very perfect insulation. They may also be joined in multiple arc, and so increase the quantity, or thickness of spark, but the coils must be similar in construction and force. In these cases each coil should have its own battery, but all the breaks should be screwed down, and a separate single break inserted in the circuit so as to act on all at once.

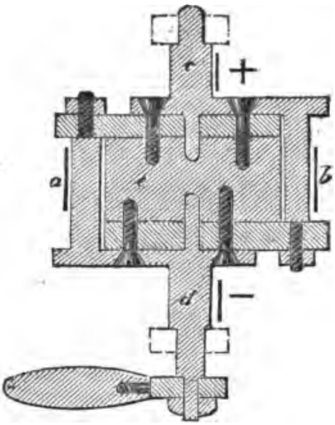
440. Mounting Coils.—In Fig. 87, *d* is a slab of glass, ebonite or prepared wood, fixed upon the ends of the reel, forming a frame the sides of which may be advantageously closed with glass, so as to protect the coil from damage by dust and damp; a tube in the middle of *d* carries a rising table of ebonite; and the two pillars + and − connected to the terminals of the secondary, constitute a universal discharger; they are, in fact, an elongated binding screw, to which wires to any apparatus may be attached. They terminate at the top with a spherical socket, forming a universal joint.

The rods, carrying wires, &c., slide in a tube, so that their distance, position, &c., are under perfect control.

In most coils these pillars, or insulated binding screws, are placed on the stand at the end or the side of the coil, but the arrangement shown is much more convenient. The two ends of the primary pass down through the stand outside the end of the reel at *b*, the inner is connected to the spring of the break, and by it to the binding screw, as shown: the outer end goes direct to the other binding screw.

It is, however, better to have a commutator on the stand to reverse or cut off connection with the battery. The best construction for this purpose is shown in full size section, Fig. 90. *e* is a circular or elliptic block of wood or ebonite, with a cheek on each side projecting beyond opposite ends of the diameter to afford a fastening for the metal portion. This consists of two similar pieces of brass, *c d*, which may be built up of several parts or cast in one, as shown. These form the axis on which the apparatus moves, and each of them being continued up one side and across the end of *e*, forms a path between two springs touching them. The cylinder is supported in two brackets, as shown in dotted lines, and to these brackets are also secured springs + and −, which being connected to the battery binding screws, bring the current to the commutator. Two other springs, *a b*, convey the current away, either being made positive according to the direction in which the handle is turned. When this is vertical, the current is cut off altogether. These springs should be fixed to small brackets with stems to pass through the foundation plate of the instrument, and are to be used in place of the principal binding screws for all connections directed to be made to these.

FIG. 90.



441. NOTED COILS.—1. *Rhumhorff* has constructed some, containing about 60 miles of secondary, which, with 1 Bunsen cell, gave $3\frac{1}{4}$ inches spark, and 16 inches with 7 cells.

2. *Ritchie* made one for Gassiot, the core 18 inches, $1\frac{3}{4}$ diameter: the wire covered with guttapercha $\frac{1}{10}$ thick: the primary, 9 gauge, 150 feet in three layers. The secondary in three cylinders, each

5 inches long, made of guttapercha $\frac{1}{10}$ thick; the wire of the middle one, 32 gauge, 22,500 feet long; the others of 33, each 25,575 feet. There are three condensers, of 50, 100, and 150 feet, capable of combination. With 5 Bunsens, each coil gave a spark of 5 inches; the three gave 12¼ inches.

3. *Siemens* and *Halske.*—Made with a great number of partitions of sheet ebonite, contained 80 miles of secondary, and gave sparks from 1 to 2 feet in length.

4. *Yeates'.*—In two compartments; core, 22 inches by 1¼; primary, 12 gauge in 2 layers; secondary, No. 36, in 55 layers, making 55,000 turns, insulated with guttapercha tissue and paraffined paper, 10½ miles in length, and 10½ lb. in weight; condenser, 66 sheets of foil 11 × 29, with paraffined paper. With 5 Grove cells it gave 12¾ inches spark.

5. *Ladd's*—Core, 1 foot long, 1·8 inch diameter; primary, 12 gauge, 50 yards in three layers; secondary, 3 miles, No. 35, in layers from end to end, each separated with five or six sheets of guttapercha tissue; condenser, 50 sheets of foil 18 × 8 on varnished paper; gives 5 inches spark with 5 Bunsens. One constructed for Dr. Robinson, with two secondary coils, each 5690 yards, or together, 6 miles 820 yards, is said to give sparks, 2·04 inches with one cell; 5·06, with two; 6·45, with three; 7·65, with four; and 8·38, with five cells.

6. *The Polytechnic.*—Length from end to end, 9 feet 10 inches; diameter, 2 feet; weight, 15 cwt., containing 477 lb. of ebonite. The core, 5 feet long, of No. 16 wire, 4 inches diameter, 123 lb. The primary, 145 lb. of 13 (·0925) 3770 yards, making 600 turns in strands of 3, 6, and 12 wires; total resistance, 2·2014 ohms.

The secondary, 606 lb., 150 miles long, and resistance 33,560 ohms, on an ebonite tube ½ inch thick and 8 feet long, the coil itself occupying 54 inches in the middle of the tube.

The condenser is in six parts, each containing 125 square feet of foil.

With five large Bunsen cells the spark was 12 inches, and 29 inches with 50 cells.

Particulars of a series of experiments with this coil are given in the 'Chemical News,' Sept. 24, 1869, No. 513.

442. **Management of Wires.**—This is of great importance, especially in constructing coils. The greatest care is requisite, for there is little satisfaction in spending much time and labour in winding up a great length of wire, and then discovering that there is a break in it at some unknown point. The following precautions, though very troublesome, will well repay the trouble.

(1) Test each reel of wire for continuity: sellers rarely furnish reels in which the wire is continuous from one end to the other.

The test requires a delicate astatic galvanometer and a cell to send current through the wire.

(2) If not continuous, wind upon a fresh reel, passing the wire through the fingers and carefully watching it. It is best to use a tin reel for this purpose, or, at all events, to use a metallic axis against which a spring can be placed, soldering the beginning of the wire to the reel. By this means a permanent test can be kept up, and measurement of resistance, length, &c., can be made at any time.

(3) It is desirable in many cases to paraffin the wire. It should be first well baked till all moisture is driven off, and while hot should be dipped into the melted paraffin, or this may be poured over it. For fine wires the paraffin may be thinned with turpentine, which will prevent the wire from being much enlarged. It is desirable to warm the reel of wire when it is about to be used, so as to soften the material.

(4) The resistance of the wires should be taken and noted, then by measuring that of a known length, the length of wire used for any purpose may be nearly ascertained.

(5) In winding up coils, &c., it is very desirable to ascertain the exact number of turns the wire makes: this may be done with a revolution counter, easily made up from such wheels as are used in gas-meter indices. This may be actuated either by an attachment direct to the end of the axis of revolution, or by an electro-magnet actuated at each revolution by an ordinary circuit closer.

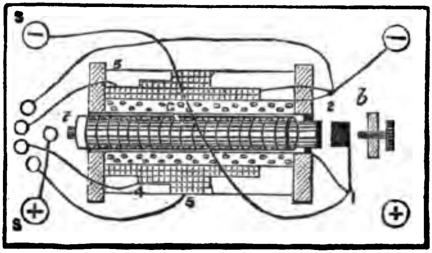
(6) With fine wires a constant test for continuity should be maintained. The beginning of the wire of the instrument should be connected to a metallic cylinder on the axis, against which a spring should press, as in (2) above. This spring and that of the wire reel are connected to a galvanometer and a battery: if a commutator is used, the current need not be continuous, but a test current can be sent through at intervals, or on completing each layer. This affords also a check upon the insulation, as any accidental contact will reduce the resistance, which ought to increase continually as the wire is strained by winding.

(7) All joints should be carefully made, stripping the wire, cleaning it, and tapering the ends, tinning them and carefully cleaning off any flux; fine wires should then be carefully twisted together and soldered, which is best done by means of a piece of No. 10 copper wire in a handle. If the wire crosses a gas flame, the point beyond (being well tinned) will act as a convenient soldering-iron for very fine work. The joint should be carefully covered without increasing the size of the wire; this may be effected by rubbing over the warmed wire a stick of cement made of gutta-percha and resin melted together.

443. **Medical Coils.**—These depend on the same principles as inductive coils, but they are made to give a current of comparatively small force but of larger quantity. For this purpose the "extra" current of the primary itself should be utilized, and stouter secondary wires employed. A great variety of arrangements are employed, vertical and horizontal. Fig. 91 shows the most convenient plan, in which a current in one direction only (that of breaking circuit) is given off. By means of the commutator which employs different lengths of wire, the energy can be varied, and the sliding tube over the core controls the force of the shock produced with the greatest nicety. The action of this tube is, practically, to shorten the core as far as it covers it, so far as its inductive reactions are concerned, by enabling the induced current to form in the tube itself instead of in the wire outside it. The following particulars relate to a coil 6 inches long in the core.

On a mandrel about an inch diameter, slightly tapering, make a pasteboard tube of three or four thicknesses of brown paper, and form a reel by gluing on this two turned ends of 3 inches diameter, leaving a space of 5 inches between them. There should be a groove on the inner faces of the ends towards the edge which is to be secured on the stand (and which is there slightly flattened) for the wire ends to lay in. Lay on four continuous layers of No. 18 cotton-covered wire, and bring out several inches of the ends, calling the inner end 1, and the outer end 2. To 2, just where it leaves the coil, join a length of No. 22 or 24 wire, which will commence the secondary; when four layers of this are placed, bring out the end, calling it No. 3, and joining to it, as before, a continuation of No. 26 or 28, calling its outer end No. 4; to which, if desired, a further length of finer wire may be added. All the wires may be cotton covered, and should be soaked with paraffin before or after laying.

Fig. 91.



A brass tube, *t*, Fig. 91, is cut to slide freely within the central tube, and at one end a thin piece of tube or metal is soldered within it, to serve as a stop; a bundle of soft wires is then packed within the tube, and a ring fitted upon its inner end to abut against that just described, and a handle, *t*, fitted to the tube itself at the same end; the other end of the core is then passed through and secured to the farther end, *b*, by wedging and cement, and trimmed off smooth to work the break, *b*, which is similar to that described § 437. Fig. 91 explains the connections; + and − are the battery screws; + is connected to the screw of the break, and the inner end of the primary, 1, is connected to the spring, which is also connected to *s* −, one of the secondary binding screws; the end 2 of the primary is connected to − for the battery circuit, and also to the first stud of the commutator for the secondary circuit. The secondary wire is shown in stages and numbered; it begins at 2, by being soldered to the end of the primary; the ends of the various lengths, 3, 4, 5, are taken to successive studs of the commutator, the central spring of which is connected to *s* +. The commutator takes up either the "extra" current from the primary, or that with the added effect of the lengths of secondary according to the stud on which the spring is placed. As arranged, that secondary binding screw will be +, which is on the same side as the primary screw connected to the + pole of the battery: the current taken up is in the same direction as that of the battery *in the coil*, therefore if the inner end of the wire is so connected as shown, the outer end is of course the + conductor from the coil. The effect of this mode of connection is, that when contact is made, the battery offers a path of much lower resistance than the body; therefore the current induced at making contact does not pass through the body, which, transmitting only the current of breaking circuit, is subjected only to the influence of a current in one direction, which is considered of great importance in some cases.

444. Electric Bells.—These domestic conveniences are very simple and easily made and fitted up. The bell arrangement consists of an ordinary clock bell, or a spiral of steel wire screwed on a stand, with a clapper spring on which there is an armature which is attracted by an electro-magnet, so that each passage of current strikes one blow. If preferred, an arrangement similar to the break of a coil (§ 437) may be used, which will give a succession of blows as long as the circuit is closed: a small magnet of quarter-inch iron bent to a horseshoe of 2 inches is sufficient. The size of wire depends on the battery power used and on the distance of the bell from the points of contact. If this latter is great, fine wire must be used, such as 26 or 28, but usually 22 is suitable. The most convenient battery is the manganese, of which three or four in series will generally suffice. The contact is closed by a spring which is pressed down on a stud, the faces in contact being armed with pla-

tinum. These "pushes," as they are called, can be readily obtained, got up in various styles of ornamentation.

The wires should not be too fine, not less than 18: two are required, but only one need be insulated, though it is better for both to be. Guttapercha-covered wire is often used, but this perishes by action of the air. Cotton-covered wire thoroughly dried and soaked in a hot mixture of four parts paraffin, one or two parts beeswax, and one part boiled linseed oil, and then dusted over with whiting, will usually answer perfectly. When several bells are in use, each requires a wire to make its circuit, but a single return wire will serve for all.

For a signal on a door opening there are a variety of modes of making contact: the simplest is a quadrant of metal above the door, with a spring pressing on it attached to the door, and an insulating piece to cover the metal of the quadrant and break circuit, except when the door has opened. A similar fitting to a window consists of a slip of metal on the side frame and a spring on the sash.

445. *Alarms.*—These may be so arranged that while a bell on each acts as just described, a complete general circuit shall also actuate a bell in one spot to indicate whenever any one of the points to be guarded is either opened or not secured. This latter is effected by a contact at each spot adapted to each place, and may be made either by pushing a bolt or hooking on a flexible wire at each part, the circuit being continued through all. In this case a current must be kept constantly passing, and its *stoppage* actuates the alarm. It is wise, therefore, to use a "relay," that is, a small but powerful electro-magnet of fine wire, which does not itself actuate the alarm, but closes a "local circuit," that is to say, a separate battery and bell; by this means a very small current may be made to serve. With a house so fitted, the security of the house is tested by the master on retiring, by having a commutator in his bedroom, which makes the final contact to the battery of the two circuits, when the arm of the relay will be at once moved and the local circuit broken if all the contacts are properly secured, and if not, the particular bell of that door, window, or room, if such are provided, will indicate the neglected point.

446. THE ELECTRIC TELEGRAPH.—This subject it is not necessary to go into at all, as it is cursorily sketched in every work on electricity, and practical knowledge can be given only by the technical works. It is essentially an application of principles fully explained throughout this work, and resolves itself into three distinct systems.

(1) *Indicatory*, such as that of the needle instruments, which are to all intents simply galvanometers.

(2) *Recording* or *Mechanical.*—Such are the Morse and the print-

ing systems, as well as those alphabetical instruments which do not record, but make a temporary indication. All these are actuated by electro-magnets working or releasing clockwork. Some of these also work by sound, the taps of the electro-magnet answering to the contacts made.

(3) *Chemical.*—These work by electrolysis, producing coloured marks when current is passed to the electrodes, one of which is a revolving cylinder, the other a point, a sheet of paper moistened with the electrolyte being interposed and drawn between the cylinder and the style.

The telegraph system is, therefore, simply the effecting of common electric actions at a distance, and is wholly a matter of resistances, and delicacy of instruments fitted to work with small currents.

447. *Duplex Telegraphy.*—This, the causing two messages to be transmitted by one wire in opposite directions at the same time, is a refinement only very recently practically effected, though the principles have been known for years. It depends upon a very careful balancing of resistances: the currents do not pass each other at all, but if signals are sent simultaneously, the effect is that the receiving instruments are really worked by the batteries of their own station, not by that of the sending station.

The instrument is essentially an electro-magnet wound with two wires exactly as a differential galvanometer, § 182, p. 135, and acting upon the same principles. In one circuit is connected the line wire, and to the other a resistance equal to that of the line. Currents sent into this instrument from its own end will therefore not actuate it, as they divide into two equal parts; but a current entering by the line will actuate it, for (1) the station itself is *not* sending a current, then the line current passes through one circuit to the junction and back through the other, through a double resistance, but with double power, and so works the instrument in the usual way. (2) The receiving station is also sending, then according to the direction of the currents, one of the two circuits contains an additional or an opposing electromotive force, and thus an extra portion of the current enters one of the circuits and thus actuates its own instrument. The two instruments at opposite ends of the line being alike, and the resistances properly balanced, it will be seen that the operator at A station always sends his signals into his own instrument, but these do not affect it unless B is also sending signals into it, and therefore each operator only sees upon his instrument the result of the signals transmitted by the other operator, although they may be actually produced by his own battery set in motion by himself. In the case of submarine cables, there is, besides the line-resistance, the temporary and vanishing resistance due to "Charge," § 395, p. 320, and to work on the duplex system a similar condition must be produced in the secondary or home circuit. This is effected by using, with the resistance equal to that of the line, condensers equivalent to the charge the cable is capable of taking up.

448. **Edison's Motograph.**—This is the latest *new* idea or discovery in electrical actions, and it would appear to be likely to lead to many developments. The following is Mr. Edison's own description:

"In my new system of telegraphy it would seem that power was obtained, or that electricity had been passed into a new mode of motion, as with magnetism; but this is only apparent, not real, if I understand it aright.

"The electricity acting by electrolysis changes the nature of the surface of the paper, either by depriving it of some constituent, or the hydrogen in conjunction with the metal and paper form substitution compounds, the surfaces of which are smoother than the paper in its natural state, in the manner that the surface of rough paper is made smooth by dipping it into sulphuric acid. The strangest thing connected with the phenomenon, however, is this:

"In trying to ascertain what caused the lever to move, whether it was reducing the lead by hydrogen to a finely-divided powder that acted as a lubricant, or whether the nature of the surface of the lead were changed by the absorption of hydrogen, like palladium, or whether the effect were due to the effort of the gases to escape from under the lever, I was led away from these notions by finding that platinum with sulphate of quinine will likewise show the movement. It then struck me that the nature of the paper was changed by the electrolysis. To test this I had a long message received over the automatic telegraph wire from Washington (this wire runs in my laboratory at Newark), and recording the same on ordinary chemically-prepared paper. The speed with which the message was sent from Washington was 800 words per minute, and the colourations forming the dots and dashes were rather faint. I then passed the strip into the electromotograph (I use this name for want of a better one), the colourations being in a direct line with the lead point. On rotation of the drum, and when no colouration was under the point, the lever was carried forward by the normal friction of the paper. But the moment a colouration passed under it the lead point slid upon the paper as upon ice, the friction was greatly reduced, and the lever moved in an opposite direction to the rotating drum.

"In this experiment no battery was connected to the instrument. This proves that electrolysis produces a change in the nature of the paper.

"I afterwards found that if a tin pen were used to receive a message from Washington, although no marks were seen, the paper appearing unchanged, yet on passing the paper through the instrument the movement of the lever was more marked than before. Receiving the message with a lead pen did not give so good results, although lead is the best when used, standing at the head of the twelve metals tried. The next is thallium. On paper moistened with aqueous solution of pyrogallic acid, tin is as good as thallium. Of all solutions yet tested, potassic hydrate has been found to give the most marked results; the second best is sulphate of quinine; third, rosaniline, oxidized and discoloured by nitrous acid.

"A peculiarity of the quinine solution is that platinum shows an action, and shows it when either oxygen or hydrogen is evolved on its surface. With hydrogen the friction is lessened as with all other metals, but with oxygen the friction is increased. This is so with all the metals subject to oxidation; but it appeared strange at first, that it would show with a metal upon which the nascent gases had no effect.

"With a lead point and a solution of the disinfectant known as bromochloralum, the evolution of hydrogen increases the friction of the paper enormously.

"Silver seldom shows a movement with any solution, and when it does it is very weak.

"Sulphuric acid shows less movement with any metal.

"It appears to be a matter of indifference as to the character of the metal used for the drum which acts as one of the decomposing electrodes. Considering that the lever will close a secondary circuit under the great pressure used upon the lever, its sensitiveness to electricity is wonderful. With a delicately-constructed machine, moved by clockwork, which I have nearly finished, I have succeeded in obtaining a movement of the lever sufficient to close the local circuit with a current (through 1,000,000 ohms, equal to 100,000 miles of telegraph wire) which was insufficient to discolour paper moistened with potassic iodide, or move an ordinary galvanometer needle. Messages may be read from the sound of the lever, when the most delicate telegraph magnet shows no current.

"The uses of the instrument are many; in fact, it gives an entire new system of telegraphy.

"As no secondary currents are generated as with an electro-magnet to prevent the instant magnetization or demagnetization of the iron cores, it is obvious that the lever will respond to signals transmitted with great rapidity. I have succeeded in transferring signals from one circuit to another at the rate of 650 words per minute; hence it may be used to repeat the rapid signals of the automatic telegraph into secondary circuits. By attaching an ink wheel to the extremity of the lever, opposite a continuous strip of paper moved by clockwork, messages transmitted at a speed of several hundred words per minute may be recorded in ink. By attaching a local circuit to the repeating points, and adding thereto a sounder, it may be used as a Morse relay to work the long lines of telegraph."

It will be seen that this system enables motion and sound to be produced at a distance without the aid of electro-magnets or of any mechanism to be actuated by the current itself, as the motion of the drum is produced by mechanical means at the receiving station. The instrument was shown at work at the Conversazione of the Society of Telegraphic Engineers, on the 2nd December, 1874, and excited much interest.

449. Automatic Transmitters.—There have been many forms of these patented, but all are modifications of that first introduced by Bain to work his chemical receiving instrument, which is the basis of the "motograph." In principle the transmitter and receiver are the same. In each a revolving drum or cylinder rotates under a metallic style; in the receiver these are separated and yet electrically connected by a paper moistened with an electrolyte which permits currents to pass, and by the change of colour produced records the time during which current passes, and in this manner effects signals. In the transmitter a strip or sheet of paper is interposed, which is perforated at the proper times to permit the point to touch the cylinder, and allow the current to pass: thus the marks on the receiving paper correspond to those perforated in the transmitting paper. But by the same means any kind of receiving instrument can be worked, as all transmitting instruments depend upon the

making and breaking contact in one or more circuits for different graduated intervals, and the paper can be arranged to effect this mechanically. In other cases a sheet of metal is used, either as a cylinder or in a flat form, and is written upon with an insulating varnish. The style traversing over this sheet in a succession of close lines produces upon a paper at the other end, moved with the same velocity, marks which reproduce the original writing or drawing.

The advantage of mechanical transmission is that while the preparation of the message takes, of course, much longer than the direct process, many such messages may be preparing at the same time. But the actual transmission along the wire is limited only by the capacity of the receiving apparatus to record the signals, so that one wire and set of receiving instruments will do the work of many worked by hand.

Similar apparatus has been devised to actuate musical instruments, and, with more success, to record on a moving paper the notes produced by a performer.

450. **Electric Organ.**—In this the access of air to the several pipes or reeds is controlled by an electro-magnet attached to each, instead of by rods and levers actuated by the pressure on the keys. The keys themselves have no mechanical work to do; they are simply "breaks," and act by closing the circuit of a wire from each key to its corresponding electro-magnet. The work of the performer is therefore far less laborious, and his touch much lightened, while the keyboard not forming a mechanical part of the instrument, it can be placed in any convenient spot, or, in fact, at any distance whatever from the music-producing instrument.

If a chemical receiving instrument is arranged with a style and connecting wire for each key and stop of an organ, &c., and a broad strip of suitable paper passes under them, when the key is pressed down a mark is produced, which thus records exactly the kind and duration of every musical note produced. The keys of a pianoforte, and indeed of most instruments, can be similarly fitted so as to record, exactly as produced, the musical thoughts or experiments of the composer, or to exhibit to a teacher, if required, the progress and work of a pupil while practising.

CHAPTER XIII.

DICTIONARY OF TERMS.

THIS chapter is intended to supply concise definitions of terms for occasional reference or to recall their full explanation to the mind, but in some cases information is given on subjects not noticed in the other parts of the book.

AMALGAMATION.—Zinc is protected from waste by having its surface coated with mercury. For the process with zinc, see p. 87.

ANION.—The electro-negative or chlorous radical of the salt or acid decomposed. Oxygen, acid radicals as chlorine are anions (see Ions).

ANODE.—The positive electrode or pole of a battery; the wire or plate connected to the copper or other negative element of the battery; the plate which leads the + current into a solution to be decomposed, and at which are set free the oxygen, acid radicals, and all – ions (anions). In electro-metallurgy it is usually formed of the metal to be deposited, in which case it is called the soluble anode or pole.

ATOM.—The supposed ultimate particle of the elements, p. 2.

There is still much confusion as to the terms atom and equivalent, which were formerly used for the same purpose, but modern chemistry attaches a distinct idea to the atom, which correlates it, not only to chemical affinity, but to heat and other forces.

ATOMIC WEIGHT.—The relative weights of the atoms as compared with that of hydrogen taken as 1. At p. 212 is a table of the atomic weights and other particulars of the elements most important in electricity.

BASE.—See Radical.

BATTERY.—A combination of voltaic cells. The word is commonly—but erroneously—used for a single cell (e.g. Smee's battery), but it strictly means two or more cells coupled together in series. For the laws regulating the combination, see Electromotive Force, Resistance, Current, Cell. For full description of the different forms, see Chapter IV., p. 77.

BREAK.—See Commutator.

Bridge.—Wheatstone's. An apparatus for measuring resistances by balancing the unknown R against one known and capable of regulation, p. 168.

Calorimeter.—Instruments for measuring heat produced; for electrical uses, they are in fact simple thermometers, as described p. 142; but for the measuring the heat produced in chemical actions, &c., very elaborate instruments are made, as described in treatises on Heat.

Cathode.—The negative pole of a battery; the wire or plate connected to the zinc; the plate at which, in any decomposition cell, the cations or + ions are set free. In electro-metallurgy, the object upon which the deposit is to be formed is the cathode.

Cation.—Electro-positive elements and radicals, which are set free in electrolysis at the cathode. Hydrogen and metals in the order of the electro series are cations (see Ions).

Cell.—Each separate vessel in which a chemical action occurs, forming part of the electric circuit. Thus there are the active or generating cells—i.e. those which form the battery, and the decomposition cells, and these last may be of two classes: (1) Passive or mere resistances, such are those employed in electro-metallurgy where the metal is dissolved from the anode, and simply transferred to the cathode; (2) where chemical force is exerted and absorbed in effecting true decomposition, as in the voltameter.

Chemic.—See Units of Current.

Chlorous.—Pole, a term sometimes used for the negative pole or cathode. Chlorous radical is that radical of a salt or acid which answers to chlorine in HCl—that is, it is the acid radical or electro-negative element or anion.

Circuit.—The path along which the current travels, or in which electric tension is set up.

Conductive circuits are those through which current passes, and are composed wholly of conducting materials.

Inductive circuits apply to static electricity, and are partly composed of insulating materials, as air or condensers.

We may conceive a conductive circuit as represented by an endless chain driven by a drum to which force is applied (this representing the generator); such a chain will drive any machinery to which it is connected, as the current does work. The inductive circuit resembles more a single chain acting on a spring, like a bell wire, so that only single impulses can be given, and on release the spring restores the energy.

Derived circuits are a division of the path in two or more parallel branches.

Commutator.—Break, contact breaker, and circuit changer. They are of many forms, according to the purpose required; a simple spring pressing on a point serves for a mere break or interrupter of the current, but the arrangement is often complicated when it is necessary to provide several different circuits for the current.

CONDUCTIVITY.—The degree of power to permit current to pass; it is the opposite of "Resistance," which see.

CONDUCTORS.—Substances which permit electricity to pass. It used to be thought that substances were of two distinct classes, conductors and insulators; but it is now known that it is only a question of degree of resistance. Silver is the best conductor, then other pure metals, then alloys; solutions of electrolytes follow, but at a long interval. Current passes through conductors in the ratio of their sectional area, and the inverse ratio of their length.

CONNECTIONS.—Wires, &c., completing the circuit between different apparatus; they should be sufficiently large, and of copper, so as to give little resistance. There is often much trouble caused by the stiffness of stout wires, it is, therefore, well to form a spiral upon each connection, so as to give a little elasticity. The best connections, however, are made of wire cord, such as is made for window sash-line, or by twisting up fine copper wire into a cord; lengths suited to various purposes should be cut, and to the ends should be soldered pieces of No. 12 copper wire, of a couple of inches long, for insertion in binding screws. If these ends are well silvered or gilt, much trouble in cleaning will be saved. Annoyance from accidental contacts, &c., is also avoided by covering these conductors with narrow tape plaited on, and soaking with boiled oil.

CURRENT.—This word is used in many ways. The electric current means the supposed flow or passage of electricity or electrical force in the direction from + to − or positive to negative. It, therefore, originates at the zinc surface in contact with the solution, and passes from the zinc to the copper or other negative metal *in the liquid* of the battery, but *from* the negative metal to the zinc in the external circuit (see Positive and Negative). *Current* also means, scientifically, the measured work done chemically, or what was formerly called "Quantity" (which see, also Intensity of Current). For the laws governing this, see Ohm's Laws and Units.

In electro-metallurgy an important consideration is the *density* of the current—that is, the relation of the actual or total current passing, to the surface or area of the anode and cathode. It is the *current* or quantity alone, and entirely irrespective of the force developing the current (i.e. intensity in the older books), which affects the amount of work done chemically, or which is measured either by the galvanometer or the voltameter. The electromotive force or tension (or intensity) is concerned only in producing the current against the special resistance in each case (see Tension).

Density.—See Current.

Electrodes.—Faraday's term for the poles or plates leading the current into and out of a cell. (See Poles, Anode, and Cathode.)

Electrolysis.—The act of decomposition by an electric current. *Secondary* electrolysis is a decomposition supposed to be effected by the chemical action of the substance really set free by the current (see Nascent). For explanation of this action, see p. 256.

Electrolytes.— Bodies capable of being decomposed by an electric current. They must be composed of (or rather be capable of breaking up into) two radicals (see Ions); therefore, substances which contain three or more radicals are not electrolytes.

Electrometer.—Instrument for measuring electro-static charge, or tension.

Electromotive Force.—The tendency to develop electric tension; in ordinary galvanic batteries the electromotive force is set up by the attraction of zinc for an acid radical; its degree depends upon the force and number of such chemical affinities in the circuit, and inasmuch as there are also opposing affinities tending to develop electromotive force in the opposite direction, the actual force depends upon the excess of the total affinities in the direction of the current, over those in the opposite direction.

Electromotive force may be either continuous or intermittent. Galvanic batteries and frictional machines set up a continuous E M F, which may be compared to gravity in its actions and laws.

Revolving magnets, charged condensers, the secondary wires of induction coils, set up a variable E M F, which may be compared to the energy of impulses and with the laws of projectiles. Such intermittent forces require a different mode of consideration and of measurement from those of a constant E M F, although the same fundamental principles apply to both.

Elements.—The ultimate substances into which all the bodies we know can be resolved, and which, themselves, have not been resolved into any simpler bodies. There are 63 elements known, and two or three more suspected. They are assumed to exist in the form of *atoms*, and further information will be found under that head and under Equivalents.

Endosmose.—The power possessed by liquids and gases of diffusing into each other when separated by a partition or septum of animal membrane or unglazed earthenware. Electric endosmose is this action, greatly heightened by the passage of an electric current, which will frequently raise the liquid on one side of the partition several inches above the other. The laws ascertained by

Weidemann are (1) the quantity of liquid which flows out in equal times is directly proportional to the strength of the current; (2) the quantities flowing out are (all other conditions being equal) independent of the size of the porous substance; (3) the height to which a galvanic current causes a liquid to rise is directly proportional to the extent of the porous surface; (4) the force with which an electric tension present on both sides of a porous division, or in a liquid, urges the liquid from the positive to the negative side of the partition, is equivalent to a pressure proportional to that tension.

The action is very troublesome in batteries, in which the liquid in the zinc or positive cell is transferred to the negative cell. Ordinary endosmose at the same time transfers the liquid of the negative cell to the zinc, causing local action, as when the copper solution of the Daniell cell enters the porous vessel.

EQUIVALENTS.—All chemical actions take place in a definite ratio, which is explained by the atomic theory as due to the combination of 1, 2, or more atoms of one substance or element, with 1, 2, or more atoms of others. Each element has its own equivalent weight, as compared with hydrogen, as 1. There is much confusion of ideas, due to the change of modern chemistry from the old system of stating reactions in *equivalents* to the modern system of stating them in *atoms*. Table XIII., p. 212, gives a list of the equivalents. The relation of electricity to these equivalents is such, that in a chain or circuit composed of any variety of compounds of two of these bodies (which are, in fact, elements, radicals, and ions), the same current would release from combination the relative weight set against each substance. The weights themselves are relative or abstract, but in this work they are taken as "grains," for the purpose of getting a definite electric measure of current and work.

EQUIVOLT.—A unit devised by the author to connect together tension and quantity. It is the force engaged in effecting 1 equivalent of chemical action in a circuit of 1 ohm resistance, and under the volt electromotive force. It is described § 258, p. 217. Its mechanical equivalent is 4673 foot-pounds. This unit, when thoroughly comprehended, will greatly aid in understanding electricity, and the doctrine of the correlation of forces.

GALVANOMETER.—An instrument for measuring "current" by its magnetic effects in deflecting a magnetic needle. They are not comparable among themselves unless graduated for the purpose. The tangent and sine galvanometers are proportional, so that knowing the value of any one deflection that of all others may be calculated. The Patent Universal Galvanometer, p. 133, shows on its dial the current passing or work doing, and the resistance of the circuit, in definite units.

Induction.—This is the name given to effects produced outside of the body exerting a force or out of the circuit to which the force is directly applied. Thus a magnet induces magnetism in neighbouring magnetic substances, and then attracts them.

A static charged surface is said to induce an opposite electric charge upon surfaces presented to it; as to which see p. 29.

A current in a wire induces currents in other conductors parallel to it (see Secondary).

Insulators.—Bodies possessing high resistance; all, however, allow some current to escape or rather "charge," to be lost as current. They are called "electrics," because friction develops electric excitement in them. Ebonite is the highest "non-conductor;" paraffin, sulphur, and glass follow. A full list is given p. 14. Telegraphic insulators are the porcelain cups, &c., to which the wires are secured, and which prevent electric communication being formed between the wires and the earth through the posts.

Intensity.—The old term for the properties now described as electromotive force and tension. Batteries were said to be arranged for *intensity* when the cells were coupled together in series. The term leads to such confusion that it is best abandoned altogether.

Intensity of Current.—A term adopted from the French *intensité de courant.* It means "quantity;" and the best writers now use the simple word "current," to avoid the confusion of these conflicting terms.

Ions.—Faraday's term for the two parts into which an electrolyte breaks up; they may be regarded as "radicals," and may be either single atoms of elements, doubled atoms which still act as one chemically, or they may be compound radicals, like cyanogen, ammonium, and the radicals of acids. They are of two classes, named from the electrode at which they appear; but it must be remembered that the same radical may be an anion at one time and a cation at another, according as it is united with a radical more or less high in the order of affinity (see Anions and Cations).

Measurement.—See Units.

Molecule.—The ultimate particles of free or complete substances. Modern chemistry draws a strong distinction between atoms, equivalents, and molecules, terms as to which there was formerly much confusion. The true meaning is fully explained, pp. 5–8.

Nascent.—It is found that substances have a much greater chemical force at the instant in which they are being set free from combination than when they are free bodies. They are then called "nascent." Most of the processes of electro-metallurgy are usually considered to be effected by secondary electrolysis, through this action of nascent hydrogen. This special energy is supposed to be owing to substances (or radicals) being then in the atomic instead of the molecular condition, and therefore having all their chemical energy or attractions engaged in seeking a combination. It is commonly the case, also, that a radical cannot be set free at all, unless in the presence of some other bodies with which it is capable of uniting.

Negative.—In the battery, the copper, carbon, or platinum plate.

Negative Ions.—Oxygen and acid or chlorous radicals.

Negative Pole.—Cathode, platinode.

Notation.—The mode of expressing chemical substances and reactions by their symbols. There are many modes of expressing the same things in different formulæ according to the special theory of constitution adopted, or the particular view of the matter intended to be described; and there are two distinct systems in use: the atomic or new notation, and the old equivalent notation.

There are also many ways of writing formulæ. That used in these pages is the simplest known, being based upon the binary theory of salts, and showing every atom in a reaction by its distinct symbol.

Some fanciful formulæ have been used lately, for the purpose of expressing particular theories of the constitution of substances. The most prominent is Frankland's, based on the hydroxyl theory. It is exceedingly puzzling, as it does not show real atoms, but the supposed compound radicals of the theory, and as Ho and Cuo mean something different from the usual HO and CuO, it is rarely written, and never printed correctly throughout.

Ohm.—The unit of resistance, called the British Association unit (see Units).

Ohm's Laws.—These formulæ, devised by Ohm, enable us to calculate from certain data all the information we require. The symbols should represent fixed units (see Units) to obtain definite results. Otherwise they are merely comparative.

E stands for electromotive force, R for resistance, C for current. Any two of these being known we can calculate the third; thus knowing the force of the batteries to be used, and the resistance of a circuit, we can calculate the current generated, and therefore the amount of work to be effected under any given conditions.

Current .. .. .. $C = \frac{E}{R}$

Resistance . .. .. $R = \frac{E}{C}$

Electromotive Force $E = C \times R$

In these formulæ the symbols represent the total forces and resistances of the circuit, which are ascertained from their several component parts.

Paraffin.—This valuable substance is obtained from cannel coal by distillation. Another form of the substance is called Ozokerit, or earth wax. Its name (without affinity) describes its value, for it is scarcely acted on by any of the chemical agencies, acids, alkalies, &c.; it is also one of the best of insulating substances, and resistants of moisture.

If the stoppers and necks of bottles are warmed and rubbed with a piece of paraffin they will never set fast, nor will the chemicals act upon the ground glass, while the most volatile substances are perfectly secured. Labels also may be preserved from damp and acid fumes by warming them, after they are fixed and dried, till they will just melt and absorb a little paraffin when rubbed on them.

Whenever it is applied for electrical purposes to paper, wood, or insulated wire, the material should be baked perfectly dry first, and treated while hot. It has been said that copper wire is acted upon after a time, but it would appear that this is due to imperfect cleaning from the acids used in preparing the paraffin. This may be remedied by melting and stirring up with boiling water and then allowing it to cool, repeating the process with two or three waters. Pure white paraffin only should be used. For candle making it is often mixed with stearine, &c., which unfits it for electrical uses.

Platinode.—Daniell's term for the cathode, or that plate in any cell which does not dissolve.

Polarization.—The act of arranging the substances which form an electric circuit in a polar order or chain of + and − radicals, presented towards and reacting on each other. It resembles the arrangement which takes place in a number of magnetic needles which arrange themselves in an order of NS, NS.

Polarization of Plates.—This very confusing and absurd term is applied to an action which occurs whenever the current passes from liquid to solid conductors: there forms on the surface of the latter a film different from the liquid, by which there is not only a greater resistance introduced, but an electromotive force is generated, opposing that of the current, so that if suddenly connected to a galvanometer, and the main circuit broken, a reverse current will be maintained for some time. On this principle are constructed, for some purposes, what are called "Secondary Batteries" (see p. 252).

Poles.—The wires, plates, &c., leading from the battery; their name is the opposite of that of the plate they lead from; thus the zinc is the positive metal, plate, or element of the battery, but the wire leading from the zinc is the negative pole.

Positive.—In the battery, the zinc plate; in a decomposition cell, the anode.

Positive Pole; +, the anode, the zincode, by which the current enters another cell.

Positive Ions; hydrogen, metals, and basic radicals.

Potential.—A mathematical term much misunderstood and misapplied (see § 205, p. 154).

The *Potential* of a battery means its electromotive force.

The *Potential* of any point usually means its tension above or below "earth" or "zero." Sir Wm. Thomson's definition of Potential is, "The Potential for any point A in space is a quantity depending on the position and electrical state of all bodies which act at the point A, for the present confined to all electrified bodies in its neighbourhood, and such that the difference between the values of the potential at the point A, and the potential at any other point B, is a measure of the tendency of electricity to flow from A to B, or *vice versâ*, supposing A and B connected by a small conducting wire. It follows from this that, when there is equilibrium, the potential at every point of an electrified insulating conducting body, including every other insulated conducting body connected with the first by wires or other conductors, is the same, and may be measured by connecting, by a conducting wire, any part of the conducting body with any insulated electrometer of sufficient delicacy."

Quantity.—A term based on the idea that electricity is an actually existing element having quantitative relations to chemical actions similar to the atomic weights of the material elements. The definition applicable to existing ideas of the nature of electricity will be found under "Current."

Radicals.—Either elementary atoms, or compound bodies which act like atoms, retaining their completeness and individuality through a series of chemical changes. It is considered that the acids are formed of such radicals whose attractions are satisfied by hydrogen, while salts are the same radicals satisfied by metals or compound basylous radicals. These radicals are the *ions* of the theory of electrolysis.

Reduced Length.—A term sometimes used to express a resistance in the terms of its equivalent length of wire or resistance.

Resistance.—The opposition presented by the circuit to the development of the current; it is an inherent property of every substance, varying in degree in each substance, from silver, the best conductor, up to guttapercha and the other so-called nonconductors. Whatever the special substance however, its actual resistance may be expressed in any common unit; thus we may describe the resistance of a decomposition cell as equal to so many feet of a given wire. The unit of resistance now generally employed is the ohm.

Resistance requires to be considered in the various sections of the circuit as "internal," that of the battery itself; and "external," that of the work to be done, the conductors leading to it, and any measuring apparatus employed.

Resistance, when it is not work in some form, always converts the energy of the current into heat (see 'Ohm's Laws and Units').

Retardation.—A term applied to the inductive action which reduces the rate of signalling in submarine cables. A signal to be transmitted requires a current at the receiving end adequate to the mechanical work to be performed in the instruments. The amount of that current is measured by the well-known Ohm's formula. But that current is not obtained in the receiving instrument at the instant of making contact at the transmitting end. A charge has to be given equivalent to the inductive capacity of the cable, and this charge acts as a resistance, great at first, but gradually diminishing to nothing. During this process the current at the receiving end increases as the momentary value of this inductive resistance diminishes, till it reaches the amount due to the ordinary wire resistance of the circuit.

Rheostat.—A measure of resistance. The name is usually given

Secondary Wire, in coils, is the long and fine outer wire in

to Wheatstone's instrument, p. 157.

Secondary.—An action or a circuit depending on another.

Secondary Action.—See Electrolysis.

Secondary Battery.—See Polarization of Plates.

which the induced current is set up by the magnetic reaction of the core.

Tension.—The strain put upon the circuit by the electromotive force; it may be regarded as a single amount, or as + and − equal in opposite directions from the source. At the source it is equal to the electromotive force; calling this 100, it falls throughout the circuit in exact proportion to the resistance; it is, in fact, used up in passing the current against the resistance; the effect of tension is explained, p. 164.

Units.—The various bases of any system of measurement.

The Absolute are based upon the units of mass, length, and time, 1 gramme, 1 metre, and 1 second; the fundamental unit is that force which can generate a velocity of one metre per second; gravity being a force of 9·811 such units (or 32·2 ft. per second). For practical use larger units have been devised by the British Association, viz.:

Electromotive Force and Tension.—The volt = 10^5 or 100,000 absolute units. The Daniell's cell, that is, the chemical affinity of zinc displacing copper from its union with sulphuric radical, is 1·079 volts; and therefore, for rough purposes, may be taken as a volt.

Resistance, the ohm = 10^7 or 10,000,000 absolute units; ohm measures made of German-silver wire can be obtained of scientific instrument-makers, and from them instruments for measuring resistances can be made as described, pp. 158 and 171.

Current.—The veber, $\frac{10^5}{10^7} = 10^{-2}$ or ·01 absolute unit per second. 1 veber decomposes ·00142 grain of water.

The Chemic.—The unit of current is much more conveniently based upon an equivalent of chemical action, or quantitative result, and the unit used in this work is a current effecting one equivalent of chemical action (in grains) per ten hours. A current of 1 veber per second is equal to 5·68 of these units, therefore in any calculations (see 'Ohm's Laws') the unit of electromotive force (the volt) would have to be multiplied by 5·68 to give the result in chemical units, and a force calculated from these units would be divided by 5·68 to express it in volts. This unit I call a "chemic." A *chemic*, therefore, is a rate of current which in a second is equal to ·17606 of a veber, and would in ten hours deposit or set free 1 equivalent in grains of any element or ion.

Current and Energy.—See Equivolt.

VEBER.—See Units of Current.

VOLT.—The unit of electromotive force and tension (see Units).

VOLTAMETER.—An apparatus for measuring the current by its chemical action; the term is usually limited to a vessel provided with two platinum poles for the decomposition of dilute acid, and with tubes for collecting and measuring the gases given off.

ZINCODE.—Daniell's term for the anode.

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